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Determining Weight of Stockpiled Ore Using Microgravity Measurements

by Keith J. Sjostrom

Prepared for Defense National Stockpile Center

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Waterways Experiment Station
3909 Halls Ferry Road
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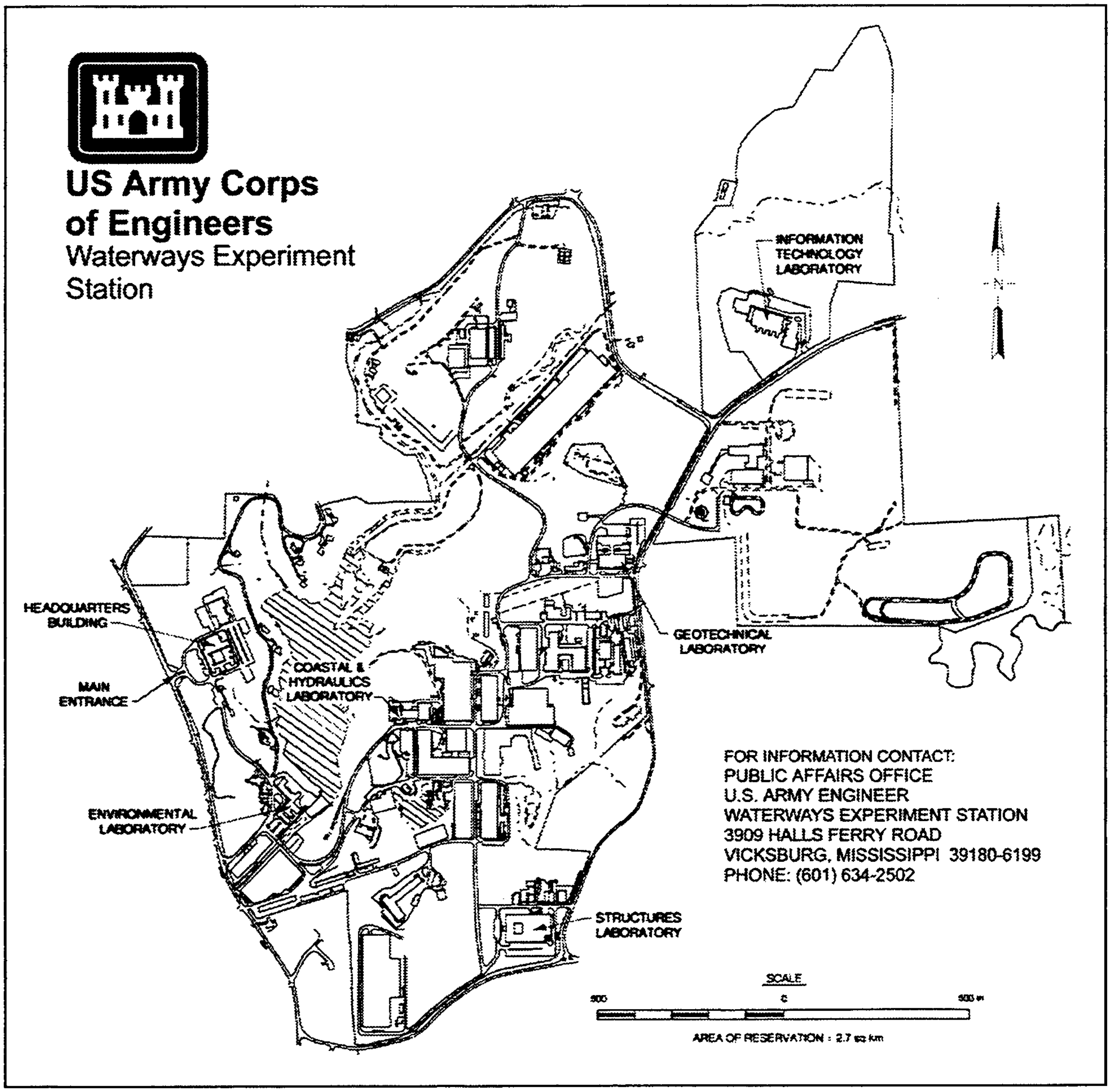
Final report

Prepared for Defense National Stockpile Center
Fort Belvoir, VA 22060



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Contents

Preface

The Defense National Stockpile Center (DNSC) maintains stockpiles of high-grade ores at various locations throughout the country and has a requirement to produce current weight estimates for selected piles as part of a national audit. A geophysical investigation to determine the material density and total weight of selected stockpiles of high-grade ores has been conducted by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES). Analysis of microgravity measurements provide representative bulk density values of the high-grade ore. The weight of each ore stockpile is computed by multiplying the average density values and surveyed ore pile volume determinations. Microgravity measurements were collected over ore stockpiles at the following locations during the dates listed:

Seneca Army Depot, NY	15-30 October 1996
Belle Mead Depot, NJ	3-8 November 1996 and 2, 3 December 1996
Large, PA	17-20 November 1996
Somerville Depot, NJ	3-5 December 1996
Stockton Depot, CA	16, 17 December 1996

The study was performed under sponsorship of the Defense National Stockpile Center, Defense Logistics Agency, Ft. Belvoir, Virginia. The DNSC Project Coordinator was Mr. G. A. Vanegas.

The overall test program was conducted under the general supervision of Drs. W. F. Marcuson, Director, GL, and A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division (EEGD). Mr. Keith J. Sjostrom was the principal investigator. This report was prepared by Mr. Sjostrom under the supervision of Mr. J. R. Curro, Jr., Chief, Engineering Geophysics Branch. Data acquisition and analysis support was provided by Drs. Janet E. Simms and Richard D. Lewis and Messrs. Donald E. Yule, Rodney L. Leist, and Michael K. Sharp, EEGD, GL. Assistance in report preparation was provided by Ms. Lori M. Davis, EEGD, GL. Graphical presentation of the ore piles was provided by Mr. Grady A. Holley, Applied Research Associates, Vicksburg, MS.

Acknowledgment is made to Messrs. Stuart B. Green, Kimball D. Slaton, William C. Butler, Anthony R. Jackson, Wayne J. Roberts, Jr., and Morris S. Woodruff, and other employees of DIMCO, Inc., Vicksburg, MS, for

surveying and determining the volume of each ore pile, providing the elevations of each gravity station, and assisting in the layout of the geophysical survey lines. The topographic surveys were performed during the periods 15 October-16 November and 16-18 December 1996.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02832	cubic meters
cubic yards	0.76455	cubic meters
feet	0.3048	meters
gal (measure of gravity)	1.0	centimeters per second squared
gal (measure of gravity)	0.01	meters per second squared
microgal	1.0×10^{-8}	meters per second squared
miles (U.S. statute)	1.6093	kilometers
pounds (mass)	0.45359	kilograms
pounds per cubic foot	0.01602	grams per cubic centimeter
pounds per cubic foot	16.0184	kilograms per cubic meter
tons	907.1847	kilograms

1 Introduction

Background

The Defense National Stockpile Center (DNSC) of the Defense Logistics Agency, Ft. Belvoir, VA, maintains stockpiles of high-grade ores at various defense depots throughout the country. While the initial or as-delivered weights of many of the piles of materials are known or have been estimated in previous years, the measures or estimates, many of which are 30 to 40 years old, may not be reliable. DNSC has a requirement from the Inspector General to produce current weight estimates for statistically selected piles as part of an Audit of National Defense Stockpile Transaction Fund FY 1996 Financial Statements. The reliability of the weight estimates are important for assessing the current ore inventory within the Federal government and for setting fair market values of the material when the ore stockpiles are sold to industry.

DNSC has requested assistance from the U.S. Army Engineer Waterways Experiment Station (WES) in determining the weight of 45 piles of heavy metal ores in the Defense National Stockpile at five locations: Seneca Army Depot, NY; Belle Mead Depot and Somerville Depot, NJ; Stockton Depot, CA; and an unmanned facility in Large, PA (see Figure 1). The pile materials are all heavy metal ores consisting of either aluminum oxide, ferrochrome (high and low carbon content), or ferromanganese. The size of the materials in the piles range from fines to boulder size.

Standard geotechnical methods for bulk density determination are not readily applied to the in-place pile materials because of the large range in size of the ore. Measuring the near-surface density values of the pile materials by a technique such as the ring density test will not give representative density values representative of the material near the base or center of the piles. Density determination methods which require displacing materials, i.e., material placed in known volume containers and weighed, are likely to produce values that are less than the actual material density.

A method for computing the weight of the in-place ore stockpiles and determining a truly representative bulk density for each pile is to measure the gravitational attraction of the piles. The gravitational attraction of the piles is the result of the integrated effect of the in-place bulk material density distributed over the volume of the pile. Analysis of the gravitational anomaly recorded over piles of ore results in estimates of the representative bulk density of the ore material. The weight for each pile is computed by multiplying the average bulk density values with the measured pile volume. Gravitational determination of near-surface densities for use in gravity survey data reductions are done routinely in geophysics. However, determination of densities by gravity surveys is a non-standard technique for the present application.

Purpose and Scope

The objectives of this investigation are to determine the in-place weight of 45 ore piles representative of the ore stockpiled under DNSC jurisdiction. The results will be used to check the current ore inventory as part of an audit of the National Defense Stockpile Transaction Fund, Fiscal Year 1996 Financial Statements. Pile volumes are determined using standard topographic surveying procedures. Material density values are derived through analysis of microgravity measurements performed over ore stockpiles. Pile weight is the product of the pile volume and material density.

Location of Test Sites

Forty-five ore piles were statistically chosen by the Inspector General's Office to be audited. The selected ore stockpiles are located as follows. Twenty-four ore piles are located at the Seneca Army Depot in Romulus, NY. The pile designations, material types, dimensions, and originally reported gross weights, as provided by DNSC, are listed in Table 1. The material breakdown by pile is as follows: two piles of aluminum oxide, nine piles of high-carbon ferrochrome, and 13 piles of ferromanganese. Eight piles of high-carbon ferrochrome are located at an unmanned storage facility in Large, PA which is located approximately twelve miles south-southeast of Pittsburgh, PA. The information on record for these piles are listed in Table 1. Twelve ore stockpiles are located at the Belle Mead Depot in Belle Mead, NJ, located approximately 10 miles south of Somerville, NJ. The 12 ore stockpiles are categorized as follows: one pile of high-carbon ferrochrome, six stockpiles of low-carbon ferrochrome, and three ore stockpiles of high-carbon ferromanganese. The pile descriptions, dimensions, and reported weights are outlined in Table 1. DNSC records list one combined reported weight value for Piles #3 (1 of 2) and #3 (2 of 2) and likewise for Piles #4 (1 of 2) and #4 (2 of 2). Two of the 45 piles selected for this study are located at the Somerville Depot south of Somerville, NJ. The piles, as listed in Table 1, are comprised of low-carbon ferrochrome and designated as Piles #3 and #4. The final pile of the study is located at the Stockton Depot in Stockton, CA. The ore pile is denoted as Pile #1 and material classified as high-carbon ferrochrome (see Table 1).

2 Principles of Microgravity Surveying

The Microgravity Method

Gravimetry is one of the fundamental methods with which to map the distribution of the subsurface geology and determine the nature and magnitude of subsurface density anomalies. Near-surface density anomalies produce localized variations in the gravitational field near the surface of the earth. Systematic measurements of the gravitational field allows the field to be mapped on the surface of the earth. The measured gravity field is corrected for variations in the normal gravitation field of the earth and any large scale gravity effects relative to the survey area of interest. The resultant values, with respect to an arbitrary reference datum, are the gravity anomaly field. Analysis of the gravity anomaly field provides estimates of the density contrast between the anomalous feature and surrounding earth material. The depth to and geometry of the localized feature are also defined.

The normal gravitational field on the earth's surface is given by 9.80 m/s^2. Instead of using the units of m/s^2 for gravitational acceleration, geophysicists often employ the unit of Gal where 1 Gal = 10^{-2} m/s^2. Microgravimetry refers to high-resolution surveys of the gravitational field with gravimeters that have a measurement sensitivity and accuracy of approximately one microgal (1 μGal). The quantity of 1 μGal = 10^{-6} Gal = 10^{-8} m/s^2. Therefore, microgravimetry involves the measurement of gravity with a precision and accuracy of approximately 10^{-9} times that of the normal earth's gravitational field. The microgravity measurements recorded for this study were completed using a LaCoste and Romberg Model D Gravimeter as shown in Figure 2. The measurement characteristics of gravimeters used for microgravity surveys are discussed in detail in Butler (1980) and Torge (1989).

Microgravimetric surveys are of two types: (a) profile surveys, where gravity measurements are made along traverses generally perpendicular to the presumed strike of a linear-type structure, such as a fault, ridge, valley, buried river channel, or an elongated pile of material on the surface; and (b) areal surveys, where gravity measurements are made at stations on a grid over an area. Microgravity surveys are often conducted with measurement points separated by 5 to 30 ft to enhance the detectability and resolution of small and closely spaced subsurface features. Station locations and relative elevations must be accurately determined by a site leveling survey in which the station locations and elevations are measured to the nearest 0.1 and 0.01 ft, respectively. The field procedures used for the surveys are dictated by considerations of survey objectives and subsequent corrections which must be made to the measured data. The measurements in a microgravity survey are normally made relative to a local reference station, and there is usually no attempt to tie the values to an absolute gravity determination.

Analysis of the surface gravity anomaly, in many cases, allows the mass excess or deficiency associated with the density contrast to be determined (Butler 1980; Telford et al 1990). When the density values associated with the density contrast and the volume of the feature are known or can be measured, then the actual mass associated with the localized feature can be determined. For unique cases where a profile of gravity measurements crosses a topographic surface feature such as a hill, ridge, or ore pile and the surface feature being investigated is entirely above some reference datum, it is possible to determine the actual bulk density of the material comprising the structure directly from the gravity measurements (Nettleton, 1940; Parasnis, 1979; Telford et al, 1990; Sjostrom and Butler, 1996). It is this last capability that is used to determine the bulk density and weight of an ore stockpile.

Field Procedures

Gravity values were collected along traverses established across the base, side slopes, and tops of each ore stockpile. The gravity survey lines were established and measured using microgravimetric procedures such as those outlined in Butler (1980). For elongated piles, the profile lines are oriented approximately perpendicular to the long axis or strike of the ore pile with two or four profiles crossing each pile depending on the pile dimensions. Each survey line consists of approximately 15 to 20 measurement stations with each station consisting of a leveled concrete pad like the one shown in Figure 3. The measurement stations are located so that at least three stations are positioned on either side of the pile on the non-ore base material to provide background gravity readings. The remaining stations are located on the side slopes and tops of the ore piles as shown in Figures 4 and 5, respectively. These are the measurement stations from which the gravity anomaly is determined and material densities derived. Typically, three measurement stations are located on each side slope with the remainder positioned on top of the pile. Horizontal spacing between stations varies from 5 to 20 ft depending on the number of gravity stations and overall width of the piles. Horizontal locations (x,y coordinates) and elevations (z coordinate) are established by electronic surveying instruments using standard topographic surveying procedures as shown in Figure 6. Horizontal positions are measured to an accuracy of 0.1 ft and elevations are determined to an accuracy of 0.01 ft using an arbitrary reference elevation. In addition to the position surveying performed for establishing the gravity survey lines, position and elevation measurements are also acquired for use in determining pile volumes.

Each gravity profile line has a base station located off the pile at the 'start' of the survey line. All elevations and gravity measurements (see Figure 7) along the line are referenced to the base station elevation and base station gravity measurement. The gravity measurements along each profile line are typically determined in two measurement programs. Following the initial gravity readings at the base station, the first measurement program consists of approximately ten measurements as the survey proceeds towards and up the slope (see Figures 8 and 9) of the ore pile, stopping at a measurement station that is located near the crest of the stockpile; often the highest elevation along the profile. Once the reading at the top of the pile is collected, the gravity survey loops back to the base station for additional readings to conclude the first program. The second measurement program for the profile line starts at the opposite end of the line from the base station and proceeds up the 'back' side of the ore pile. Gravity readings are collected until the crest is reached. This station is the same stopping point as used for the first program. After recording the gravity meter reading, the survey again loops back to the base station for the third and final set of base station readings. This two program procedure results in three sets of measurements at the base station and two readings at the central measurement point of the line. At both the Seneca Army Depot and Somerville Depot, pairs of stockpiles, each with their long axis parallel to the other, were incorporated into the investigation. The microgravity survey is then broken into four measurement programs. This procedure results in five gravity measurements at the common base station and two readings at the midpoint of each pile.

The multiple base station measurements are used for the earth tide and instrument drift corrections and data quality control. Since measurements at the base station are used as the reference data for the survey line and for correcting all other gravity measurements along the line, special care is exercised in acquiring data at the base station (Butler 1980). The two measurements at the central measurement point are also used for survey quality control. Equipment performance and time constraints are also applied to each data acquisition program. If any type of equipment problem, such as jarring the instrument or low battery output, occurs during a program, the entire program is repeated. If the survey time exceeds 60 min for an individual program, the survey line is subdivided into additional programs. However, programs are typically completed in less than 60 min. Also, if the data quality and multiple readings are not within set limits (Butler 1980), the survey program may also have to be rerun.

Gravity Data Corrections

Corrections to microgravity data are required in order to compensate for normal gravity variations at the site over the time span required for the survey. Measured values are reduced in such a manner as to imply that all gravity data are collected along the same reference datum by implementing gravity corrections for the effects due to latitude, elevation, topography, earth tides, and instrument drift. In this manner, variations in the corrected gravity values are assumed to be caused by the stockpiles of processed ore. The normal gravity variations and compensating corrections applied to microgravity data are discussed in brief below. For a more in depth discussion of gravity data corrections, please refer to Butler (1980), Telford et al (1990), or Sjostrom and Butler (1996).

Corrections for time variations (drift). Gravity values over the survey area change with time because of earth tides and instrument drift. Earth tides, like ocean tides, are caused by the orientation of the sun and moon and are of sufficient amplitude to be detected by sensitive gravity meters. Instrument drift is caused by creep of the metal components in the meter due to thermal expansion or excessive movement. Over short time periods (less than 60 min), drift due to tidal and instrument fluctuation can be assumed to be linear over time. The usual procedure for correcting for drift is to reoccupy a base station frequently and assume that the gravity values at all stations in the survey area vary in the same manner as those between readings at the base station. Differences in gravity values at the base station are plotted with respect to time to produce a drift curve. The drift correction, denoted as Δg_{zD}, for each station is determined directly from the graph. Positive drift requires a negative correction and vice-versa.

Latitude correction. Both the rotation of the earth and its non-spherical shape produce a change in gravity values as a function of latitude. For microgravity surveys, it is usually sufficient to assign a reference latitude to the base station and use Equation 1 to compute latitude corrections for all other stations. The latitude correction, denoted as Δg_{zL}, is:

$$\Delta g_{zL} = \pm \left(0.2471 * \sin(\, 2\ \phi\,) \frac{\mu Gal}{ft} \right) * \Delta s \tag{1}$$

where Δs is the north-south distance (in feet) between the measurement and base station and ϕ is the reference latitude of the base station. The correction term is added to the measured gravity value if the station is positioned south of the base station and subtracted if located north of the base station.

Free air correction. The free air correction, denoted as Δg_{zFA}, compensates for variations in gravitational attraction caused by the changing distances of the measurement stations from the reference datum. The free air correction formula is:

$$\Delta g_{zFA} = \pm 94.041 \frac{\mu Gal}{ft} * \Delta h \tag{2}$$

where Δh is the difference in elevation (in feet) between the measurement station and reference elevation of the base station. The correction is added to the measured gravity value if the station is higher in elevation than the reference elevation, and vice versa.

Bouguer correction. The Bouguer correction compensates gravity values affected by differing masses of material beneath the measurement stations caused by elevation variations. The ore material between the reference elevation of the base station and the elevation of a measurement station is approximated by an infinite horizontal slab with density equal to that of the material beneath the station. The correction, denoted as Δg_{zB}, is calculated using the Bouguer slab formula:

$$\Delta g_{zB} = \pm\left(12.774 * \rho \ \frac{\mu Gal}{ft} \right) * \Delta h \tag{3}$$

where ρ is the material density (in g/cm^3) and Δh is the elevation difference (in feet) between the measurement and base station. The quantity Δg_{zB} is subtracted from the measured gravity if the station is above the reference elevation, and vice versa.

When all of the preceding corrections have been applied to the observed gravity data, the result is the Bouguer gravity value, denoted as g_B. The Bouguer gravity value at a measurement station is given by

$$g_B = g_{obs} \pm \Delta g_{zL} \pm \Delta g_{zFA} \pm \Delta g_{zB} \pm \Delta g_{zD} \tag{4}$$

where g_{obs} is the observed gravity reading and the remaining terms are the gravity corrections discussed above. Subtracting the gravity readings recorded at the base station, denoted as g_{base}, from the Bouguer gravity values at each station using the equation

$$\Delta g_B = g_B - g_{base} \tag{5}$$

results in the Bouguer gravity anomaly. The Bouguer gravity anomaly is used in determining the density of the ore pile material whether through direct calculation or gravity modeling algorithms.

Determination of Bulk Material Density

In standard gravity surveying to determine geologic structure, the Bouguer corrections in the reduction of gravity data require a knowledge of the average densities of the near-surface rock and sediments. However, the premise of this application is to compute the material density values from the microgravity readings. Two methods were used to determine the density of the stockpiled ores. The first method, developed by Nettleton (1940), is an indirect, graphical technique to determine density. A plot of the observed gravity values that have undergone the drift, latitude, and free air corrections versus distance along the survey line is strongly correlated to the shape of the measured topography over the pile. Applying the Bouguer correction numerous times over a range of material density values, the resultant gravity anomaly curve that has the least correlation with the topography curve, ideally a correlation factor of zero, is considered to be the most nearly correct bulk density value for the ore pile material. An example of this application is illustrated in Figure 10. This method has the advantage of averaging the effect of density variations more accurately than can be done from surface or core samples (Dobrin 1976). This method works best when the near-surface material is relatively homogeneous in nature.

The second method is an analytical approach developed by Parasnis (1979) and similar to Nettleton's graphical method. Expanding Equation 5 to include the observed gravity readings and all of the gravity correction terms, we obtain the equation

$$0 = [g_{obs} - g_{base} + (\pm \Delta g_{zD} \pm \Delta g_{zL} \pm \Delta g_{zFA}) \pm \Delta g_{zB}] - \Delta g_B \qquad (6)$$

Further expansion of the Bouguer slab correction term Δg_{zB} in Equation 6 and subsequent algebra solving for the material density parameter ρ, we get

$$\rho = \frac{g_{obs} - g_{base} + (\pm \Delta g_{zD} \pm \Delta g_{zL} \pm \Delta g_{zFA})}{12.774 * \Delta h} - \frac{\Delta g_B}{12.774 * \Delta h} \qquad (7)$$

where ρ is defined in terms of g/cm^3. For a single, straight line gravity traverse over a survey area, Equation 7 resembles the formula for a straight line; i.e., y = mx - b. To solve for an average bulk density value, Parasnis considers the Bouguer gravity anomaly, defined in Equation 5, to be a random error with a mean value equal to zero (Telford et al 1990). Therefore, plotting the values in the numerator versus the values in the denominator of the first term and drawing the best fit straight line through the data points and through the origin, the absolute value of the slope will be the material density ρ. Obviously, as Telford (1990) points out, all the points will not lie on this line unless the subsurface is uniform and the Bouguer anomaly Δg_B is everywhere zero. Therefore, the best fit straight line through the data is found using least squares analysis. An example of Parasnis's method is presented in Figure 11.

Parasnis' method was used almost exclusively for the analysis of the microgravity data. Nettleton's method was used in conjunction with Parasnis' method in instances where the gravity data sets contained erratic or spurious values or when adjacent sets of piles were surveyed. However, no matter which analysis procedure is used and depending on the number of gravity survey lines performed over each ore pile, two, three, or four spatially distributed, volume-averaged bulk density values are determined for each survey. The density values are averaged to determine a single in-place density value for the ore pile material.

3 Data Analysis and Results

Determination of Ore Pile Volume

Topographic surveys to compute the volumes of the ore stockpiles were completed using standard land surveying methods. Topographic field data were acquired using a Nikon A20 total station system with accompanying data collector, theodolite, and laser rangefinder. Horizontal data were referenced to an arbitrary coordinate system at each site using the point 1,000 North/ 1,000 East (in U.S. Survey Feet) as the origin. The vertical data are referenced to an elevation of 100 feet.

The limits of the topographic survey program are determined by the location of the gravity measurement stations on and off the ore pile. This program includes surveying each ore pile from toe to toe while taking into account all ridges, depressions, and other significant characteristics on the pile surface. The base of each stockpile is determined by a planar surface passing through the elevation points along the toe of the pile. *It should be noted that any ore material below the planar surface caused by material settlement underneath the pile is not included in the pile volume determination and, hence, the ore stockpile weight.*

The acquired elevation data are analyzed using both two- and three-dimensional (2-D, 3-D) maps. The 2-D contour plots illustrate the elevation of distinct features unique to each pile. The contour plots for each pile at the five project areas are illustrated in Appendices A through E. The contour interval is one foot. Volumes were computed using 3-D surface models of each ore pile. The elevation points on the surface models are triangulated to form columnar grids in which the volume estimates for each triangulated grid section are computed between the 3-D surface model and planar base of a pile. Grid volumes are accumulated to provide a total reported volume, in units of cubic yards (yd^3), for each pile. The average volume of each pile is noted on the contour plots, listed in Table 2, and used in the weight calculation of ore material.

The registered land surveyor leading the ore pile volume determination portion of this effort established a volume determination accuracy of ± 5 percent. The volume accuracy clearly depends on the following factors: (1) number of data points used to characterize the pile, (2) definition of irregularities in the ore pile geometry, and (3) accurate determination of the base and outside edge of the pile. It should also be remembered that any portion of the ore material below grade (i.e., below the surrounding ground surface level) caused by material settlement or an irregular placement surface cannot be accounted for in the land survey volume calculation.

Calculation of Material Density

Depending on the long axis dimension of each ore pile, two to four gravity surveys are performed to determine the average bulk density of the stockpiled ore. The observed gravity data acquired along each profile are analyzed using Equation 8 and applying Parasnis' Method to compute a density value over an individual survey line. Nettleton's Method, an indirect, graphical technique to determine density, was also used to verify results. The bulk density values are averaged to determine a single in-place density value for the ore material. Since microgravity measurements were performed only over randomly selected piles rather than each, individual pile, the average density values for piles of similar ore material are further averaged to obtain a single, representative density value that may be applied to those piles in which no gravimetric surveys were performed.

Based on published examples (Parasnis 1979; Dobrin 1976; Telford et al. 1990), the ore material density determination accuracy is estimated at ± 0.2 g/cm^3 (12.4 lb/ft^3). For example, if the computed bulk material density value is 2.5 g/cm^3, this accuracy estimate translates to approximately ± 8 percent of the true value. For more dense ore pile materials, the computed density values become more accurate.

Calculation of Ore Pile Weight

Following determination of representative material density values from the microgravimetric measurements, the total weight of the ore pile material is calculated by incorporating the volume estimates of each respective ore pile. The computed weight of the ore stockpiles are computed using the equation

$$Weight = (\rho) * \left(62.428 \frac{lb}{ft^3} \right) * \left(27 \frac{ft^3}{yd^3} \right) * (V) \tag{8}$$

where ρ is the computed density of the ore material (in g/cm^3) and V is the calculated volume of the ore pile (in yd^3) above the ground surface. The total weight is given in units of pounds (lb). Based on the accuracy of the ore material density calculation and pile volume determination, the computed weight of an ore stockpile should be accurate to within ± 10 to ± 15 percent depending on the actual density of the ore material. Outside factors such as settlement of the ore material below the ground surface, irregular pile geometries, poor definition of the pile base, or poor quality gravity data will increase the error range.

The difference between the originally reported weight of each pile of ore and the calculated weight is given in terms of percent using the equation

$$Difference = \left(\frac{Calculated - Reported}{Reported} \right) * 100\% \qquad (9)$$

where 'Calculated' and 'Reported' are the respective pile weights in units of pounds (lb). In the discussion of the results, negative percent differences represent calculated pile weights that are less than the reported gross weights.

Results

The computed volumes, material density values, and weights for each pile at the five DNSC sites are listed in Table 2 and the differences between the computed weight estimate and original ore pile weights are presented in Table 3. Negative percent differences indicate that the computed ore pile weight values are less than those values reported by DNSC.

Seneca Army Depot, New York

Twenty-four stockpiles of ore were surveyed at the Seneca Army Depot and may be categorically grouped into three material types. The stockpiled ores consist of either aluminum oxide, high-carbon ferrochrome, or high-carbon ferromanganese. The pile descriptions, dimensions, and reported weights as provided by the DNSC are listed in Table 1. Elevation contour plots and photographs illustrating each ore pile are presented in Figures A-1 through A-35 in Appendix A. The results for each group of ore stockpiles are described below.

Aluminum oxide. Aluminum oxide ore is stockpiled in two piles at the Seneca Army Depot as shown in Figures A-1 and A-3. The piles are designated as Piles #40 and #43 and consist of 110,812,140 and 29,964,520 lb of ore material, respectively, as documented by DNSC. Both piles are situated on weathered asphalt pads. The pad for Pile #40 slopes gently downward towards the north (see Figure A-2) and some settlement of the ground beneath the ore pile has taken place. Four microgravity survey lines were performed over Pile #40 as indicated in Figure A-2. Each survey line has 11 gravity stations positioned on the ore material. The volume of the ore pile is estimated at 30,202.5 yd^3. The computed average material density value derived using the gravity data analysis procedures and algorithms is 1.925 g/cm^3. Using the computed averages for the material density and pile volume (see Table 2), the estimated total weight is approximately 97,997,909.8 lb. The difference between the computed weight in relation to the weight on record (see Table 3) is approximately -11.56 percent.

Two microgravity survey lines were performed over Pile #43 as indicated in Figure A-4. The average bulk density of the ore material (see Table 2) computed from the gravity data is 2.125 g/cm^3. The volume of Pile #43 determined from the elevation survey is estimated at 7,467.9 yd^3. The computed weight of the ore material in Pile #43 is 26,748,572.8 lb (see Table 2). The computed weight of the aluminum oxide varies from the reported gross weight value by -10.73 percent. However, it was noted during the field investigation that some material had been removed from the northeastern corner of the pile since the material was originally placed. If this is the case, the computed weight is likely more representative of the current weight than the percent difference value implies.

Ferrochrome, high-carbon. Nine piles of high-carbon ferrochrome are located at the Seneca Army Depot and the dimensions and reported gross weights are listed in Table 1. The piles are positioned at random with each pile situated on a weathered asphalt pad. Photographs and elevation contour plots of each ferrochrome pile are presented in Figures A-5 through A-17. The close proximity of the piles to one another made accurate determination of the pile base and toe difficult. It was also noted that along Piles #20 and #25-A through #25-C, soil, brush, and leaves covered portions of the piles whereby further hampering definition of the toe and base of the pile. Pile #49 was placed to the north of and adjacent to Pile #18 causing the toes of each pile to be within two feet of each other. The measured pile volumes are indicated on the elevation plots and listed in Table 2.

Microgravity data were gathered over four of the nine ferrochrome stockpiles. The four piles, Piles #18, #19, #25-B, and #49, were randomly selected prior to the site investigation. Three gravity surveys were performed over Piles #18 and #49, the two largest piles at the site, as shown in Figures A-6 and A-16, respectively, whereas Piles #19 and #25-B had two survey lines each. However, the quality of the gravity data collected over Pile #25-B was poor and not used in the density determination procedures. The computed average material densities from the remaining three piles ranged from 2.991 to 3.178 g/cm^3. The calculated weight for each of these piles is listed in Table 2. For the remaining five piles not surveyed with the microgravity technique and Pile #25-B, the resultant average bulk density value is determined by averaging the densities from the three piles surveyed. The average bulk density value of the ferrochrome material for Piles #20, #25, and #25-A through #25-D is 3.096 g/cm^3. The calculated weights for these piles are also listed in Table 2. The percent difference between the calculated weights and reported gross weights at the time of placement are outlined in Table 3. The percent difference values for the nine piles range from -5.03 to -27.94 percent indicating that, for each pile, the computed weight is less than the reported weight. The piles with the higher percent difference values are those piles where the extent of the pile and pile base were difficult to determine.

Ferromanganese, high-carbon. Thirteen stockpiles of high-carbon ferromanganese are located at three areas within the Seneca Army Depot. The first cluster consists of five piles designated as Piles #10, #13, #17, #23 and #35. The second grouping of ferromanganese piles, located approximately 500 ft north of the first, is comprised of seven piles denoted as Piles #11, #14, #21, #22, #34, #37, and FM-1. Pile #31 is located near Pile #40. The dimensions and reported gross weights, as provided by DNSC, of each pile are listed in Table 1. Photographs and elevation contour plots of the piles are presented in Figures A-18 through A-35 in Appendix A. Each pile is situated on a weathered asphalt pad. The piles within the first two clusters of stockpiles are positioned in two columns whereby a single pile may be adjacent to two or three other piles. This is clearly shown in Figures A-24, A-26, and A-28. The pile bases for many of the piles are in contact with the bases of adjacent piles even though the pile boundaries are crudely defined by weathered railroad crossties. This makes definition of the pile base and measurement of the base elevation difficult and may be a possible source of errors in the volume determinations. The computed pile volumes for the stockpiles of ferromanganese are listed in Table 2 and indicated on the elevation contour plot of each ore pile.

Microgravity surveys were performed over six of the 13 ore piles with the six piles randomly selected prior to the site investigation. Some modification to the original pile selection had to be done due to the orientation of the piles. The ore stockpiles surveyed during the investigation are Piles #13, #17, #10 and #23, and #22 and FM-1. Piles FM-1 and #22 and Piles #10 and #23 are adjacent sets of piles as illustrated in Figures A-25 and A-27, respectively. Four gravity surveys were performed over Piles FM-1 and #22 (see Figure A-25) with nine gravity stations placed on the ore material of Pile FM-1 and seven measurement stations on Pile #22. For Piles #10 and #23 (see Figure A-27), three gravity surveys were performed over the adjacent set of piles with nine gravity stations placed on the ore material of both piles. Each microgravity profile was comprised of four survey programs. Three or four gravity stations along each line were located off the ore material on either side of the pile set with one common measurement station located between the piles. Three and two microgravity profiles were performed over Piles #13 and #17, respectively (see Figures A-19 and A-22), with each profile consisting of two survey programs each. Analysis of the corrected gravity data from the two piles and two pile sets provided computed material density values ranging from 3.388 to 3.449 g/cm^3. The average computed bulk density value is 3.419 g/cm^3 and represents the material density of the ore not investigated with the microgravity method. The computed weights are listed in Table 2. The percent difference between the calculated weight and reported gross weight for each pile are presented in Table 3. Each of the calculated weights are less than the weights on record with percent differences ranging from -10.48 to -25.18 percent for all but one pile. Pile #34 had a percent difference of -46.25 percent. Since percent differences of 10 to 15 percent are to be expected, percent differences greater than 15 percent are likely caused by poor definition of the pile base, pile boundary, or settlement of the earth and pad material underneath the ferromanganese stockpiles.

Unmanned storage facility, Large, Pennsylvania

Ferrochrome, high-carbon. Eight stockpiles of high-carbon ferrochrome are located at an unmanned storage facility in Large, PA. The dimensions and reported gross weights are presented in Table 1. At the time of the survey, Pile #11, the largest of the seven piles, was being removed. Photographs and elevation contour plots of each pile are presented in Figures B-1 through B-15 in Appendix B. The pile volumes determined from the elevation data are listed in Table 2 and indicated on the elevation contour plot for each pile. Each pile is situated on a weathered asphalt surface except for Pile #11 which is on a concrete pad. It is also noted that the asphalt surfaces are not horizontal but slightly irregular and slope downward towards the north. The algorithms available to the land surveying contractor to model the pile base were limited to planar surfaces. Therefore, any deviations of the base from a planar surface will promote errors in the volume calculations. Piles #12 and #20 (see Figure B-4 and B-6) are also placed alongside an earthen embankment which may further contribute to erroneous volume calculations.

Microgravity measurements were performed over four of the eight piles at the site. The piles surveyed are Piles #12, #20, #26, and #28. Two to three gravity transects were performed over each pile with the number of gravity stations on and off the ore material varying greatly because of the height and width of the ore piles and physical constraints of the surrounding terrain. Computed densities derived using the gravity data analysis procedures range from 3.386 to 3.794 g/cm^3 for the four piles directly investigated (see Table 2). The average material density is 3.639 g/cm^3 and represents the bulk material density of the ore piles not surveyed with the microgravity method. The calculated weights of the eight piles of ferrochrome ore are presented in Table 2. The percent difference values between the average calculated weight in relation to the weight on record is outlined in Table 3 and, excluding Pile #11, ranges from -8.76 to +15.26 percent. The difference values for Piles #20 through #28 are each below or within the expected error range whereas, the percent difference for Pile #12 is just outside the error range with a value of +15.26. The reason for the calculated weights having greater values than the reported weights is likely poor models of the pile base caused by the sloping and irregular asphalt surface. Piles #12 and #20, situated alongside an earthen embankment, also have greater than reported pile weights and two of the three greatest percent difference values at this project area.

Pile #11 was being removed during the microgravity and topographic surveys as shown in Figure B-1. The originally reported pile weight (see Table 1) prior to removal was 63,554,860 lb. Topographic surveys to determine the volume of the remaining part of the pile were performed on 14 November 1996. Up until that day, 9,280,020 lb of ferrochrome had been removed from the northern end of the pile and trucked to a loading facility. Therefore, the reported weight of the pile at the time of the topographic measurements was 54,274,840 lb. The calculated volume of the remaining pile material is 7152.1 yd^3. The computed weight of the remaining ferrochrome material, using an average material density value of 3.639 g/cm^3, is 43,869,109.6 lb. The difference between the computed weight and adjusted weight on record is -19.17 percent.

Belle Mead Depot, New Jersey

Twelve stockpiles of ore were surveyed at the Belle Mead Depot. The stockpiled ores consist of: one pile of high-carbon ferrochrome, eight piles of low-carbon ferrochrome, and three stockpiles of ferromanganese. The pile descriptions, dimensions, and reported weights as provided by the DNSC are listed in Table 1. Elevation contour plots and photographs illustrating each ore pile are presented in Figures C-1 through C-22 in Appendix C. The results for each group of ore stockpiles are described below.

Ferrochrome, high-carbon. Pile #15, as shown in Figure C-1, is described by DNSC as high-carbon ferrochrome having a reported weight of 5,443,680 lb. The ore material is primarily cobble size and situated on a deteriorated surface comprised of asphalt overlying soil cement. An elevation contour plot generated from the topographic surveys is illustrated in Figure C-2 and the computed volume is 886.2 yd^3. Two gravity surveys were performed over the pile as shown in Figure C-2 with nine of the 17 gravity measurements along each line collected directly over the ore material. The average computed bulk density value determined from the corrected gravity data is 3.211 g/cm^3. The calculated weight is 4,796,398.3 lb as indicated in Table 2. The computed weight of the ferrochrome differs from the reported gross weight provided by DNSC by -11.89 percent (see Table 3).

Ferrochrome, low-carbon. Material classified as low-carbon ferrochrome is stored in eight stockpiles at the Belle Mead Depot. The piles are designated as Piles #2, #3 (1 of 2) and #3 (2 of 2), #4 (1 of 2) and #4 (2 of 2), #5, #6, and #8 and are situated on reinforced concrete pads. The dimensions and reported gross weights, as provided by DNSC, are indicated in Table 1. It is noted that the reported weights for both Piles #3 (1 of 2) and #3 (2 of 2) and Piles #4 (1 of 2) and #4 (2 of 2) are listed as one value for each respective pile set. Photographs and elevation contour plots of the eight stockpiles are presented in Figures C-3 through C-17 in Appendix C. Pile volumes derived from the elevation data are noted on each of the contour plots and listed in Table 2.

Microgravity surveys were performed over four individual piles with three profiles each conducted over Piles #3 (1 of 2), #5, and #8 (see Figures C-6, C-12, and C-16) whereas data was collected over two profiles on Pile #3 (2 of 2) as shown in Figure C-8. These piles were randomly selected prior to the site investigation. Survey lines typically consisted of 9 to 11 measurement stations placed on the ore material and 5 to 7 stations located on the non-ore, earth material. The gravity data sets collected over Pile #3 (2 of 2) contained several spurious values which produced suspect and/or unrealistic density values. Average density values computed from the gravity data collected over the three remaining stockpiles ranged from 3.033 to 3.211 g/cm^3 (see Table 2). The overall average density value is 3.128 g/cm^3. The computed pile weights for each stockpile are presented in Table 2. Table 3 lists the percent difference values between the calculated weights and the reported gross weights. The percent differences range from -7.46 to -21.70 percent with each calculated weight value underestimating the originally reported weight.

Ferromanganese, high-carbon. Ferromanganese is stockpiled in three piles at the Belle Mead Depot. Photographs of the two largest piles, labeled Piles #16 and #18, are shown in Figures C-19 and C-21. The third stockpile is labeled Pile #12. Each pile is situated on a deteriorating surface comprised of asphalt overlying soil cement. The dimensions and reported gross weights of the three piles are given in Table 1. Elevation contour plots and computed pile volumes derived from the topographic survey are presented in Figures C-18, C-20, and C-22 for Piles #12, #16, and #18, respectively. The pile volumes are also tabulated in Table 2.

Microgravity surveys were performed only over Piles #16 and #18. Three microgravity profiles were performed over each pile (see Figures C-20 and C-22) with each survey line consisting of 11 and 14 gravity stations positioned on the ore material, respectively. Six gravity measurement stations for each of the six profile lines were located off the ore pile. The average computed material density values for Piles #16 and #18 are 3.589 and 3.677 g/cm^3, respectively (see Table 2). The overall average material density is 3.633 g/cm^3 and is used in the weight calculations for Pile #12. The calculated weights of Piles #12, #16, and #18 are 369,867.0 lb, 23,870,566.1 lb, and 95,937,441.6 lb, respectively. The difference between the computed weights in relation to the weights on record (see Table 3) is approximately +3.34, -9.66, and -9.26 percent, respectively. The percent differences for each pile are well within the expected error bounds for this technique but the reason for the higher than expected weight of Pile #12 is uncertain.

Somerville Depot, New Jersey

Ferrochrome, low-carbon. Piles #3 and #4 at the Somerville Depot are classified as low-carbon ferrochrome with a reported gross weight, as provided by DNSC, of 9,183,109 and 5,264,000 lb, respectively (see Table 1). A photograph of Piles #3 and #4, positioned side by side, is shown in Figure D-1 of Appendix D. The composition of the ferrochrome ranges from gravel-size particles to cobbles. Each pile is situated on a reinforced concrete pad and, therefore, no significant settlement of the material beneath the pile is expected. A wooden barrier constructed of railroad crossties encompasses each of the piles and cribbing has been constructed between the two piles as shown in Figure 4. The results of the topographic survey are presented in elevation contour maps shown in Figures D-2 and D-3 for Piles #3 and #4, respectively. The estimated volume of each pile is indicated on the contour plots and listed in Table 2. Three gravity surveys, each composed of four survey programs, were performed over the adjacent set of piles with 11 gravity stations placed on the ore material of Pile #3 and seven measurement stations on Pile #4. Three gravity stations along each line were located off the ore material on either side of the pile set with one common measurement station located between the piles. Analysis of the corrected gravity data provided an average computed material density value of 3.258 g/cm^3. The calculated weights of Piles #3 and #4 are 8,499,258.7 and 5,823,779.7 lb, respectively (see Table 2). The percent difference between the calculated weight and reported gross weight, as listed in Table 3, is -7.45 percent for Pile #3 and +10.63 percent for Pile #4. Both percent difference values are well within the expected error range.

Stockton Depot, California

Ferrochrome, high-carbon. Pile #1, as shown in Figure E-1 of Appendix E, is composed of cobble size material classified as high-carbon ferrochrome. A contour map of the ore pile constructed from the measured elevations is presented in Figure E-2 and has an estimated volume of 180.5 yd^3. The pile is situated on a concrete pad. Two gravity surveys were performed over the pile (see Figure E-2) with each survey line consisting of 10 measurement stations; five of which are positioned on the ore pile material. Analysis of the corrected gravity data yielded an average material density value of 3.518 g/cm^3 (see Table 2). The computed weight of Pile #1 is 1,070,326.4 lb. The reported gross weight provided by DNSC is 1,178,760 lb which is approximately 9.20 percent greater than the average calculated weight determined from the gravity data.

Summary of Results

Comparing the gravimetrically derived weights for each ore stockpile to the reported weights provided by DNSC, it is observed that the computed weights of 24 of the 45 piles surveyed are below or within the expected percent difference error range of ± 10 to ± 15 percent as presented in Table 3. The percent difference between the calculated weights and the weight on record for another 18 ore stockpiles are just outside the expected error range. A summary of the percent difference between calculated and reported weights for the 45 ore stockpiles is outlined in Table 4. Remember that one combined weight is documented for Piles #3 (1 of 2) and #3 (2 of 2) and Piles #4 (1 of 2) and #4 (2 of 2) at the Belle Mead Depot, NJ. The computed weights of the remaining four piles have differences greater than 25 percent of the reported values. Differences between the computed pile weights and reported weights may be caused by any of the following factors:

a. The intricate geometries of some piles or pile edges are poorly defined.

b. Inaccurate elevations or models too simplistic to accurately define the pile base.

c. Inhomogeneities within the ore creating highly variable density estimates.

d. Settlement of the ore material below the originally prepared ground surface.

e. Possible removal of ore material at some piles.

f. Suspect gravity data sets due to equipment problems.

It is also possible that the reported weights for some piles may be inaccurate as was the case for at least two ore piles at the Sierra Army Depot, CA (Sjostrom and Butler 1996).

Looking more closely at the distribution of ore piles versus the percent difference error ranges presented in Table 4, it is shown that the computed weights for piles investigated at both the Somerville Depot, NJ and Stockton Depot, CA are below or within the expected percent difference range of the reported gross weights for each pile. Piles surveyed at the Seneca Army Depot, NY each had calculated weights less than the reported weights provided by DNSC. More importantly, the weight of nine of these piles were within the expected error bounds of the testing procedure. The remaining 15 piles have percent difference values greater than 15 percent. All but three of the ferromanganese piles have greater than expected error values as shown in Table 3 and this is likely caused by settlement of some of the ore material below the elevation of the current ground surface. Any material below the current ground surface cannot be accounted for with the current microgravity and topographic interpretation procedures. Poor definition of some of the pile boundaries and bases also added errors in the weight calculations. Poor definition of the pile base also contributed to the larger than expected errors for the weights of five of the nine ferrochrome piles. The two aluminum oxide piles have computed weights within the expected error range even though ore material may have been removed from Pile #43 since placement.

Six of the eight ferrochrome piles at the unmanned storage facility in Large, PA, have computed weight estimates within ± 10 to ± 15 percent of the reported weights. Five of the eight ferrochrome stockpiles have computed weights greater than the reported weights on record as indicated in Table 4. This is likely caused by the use of simple planar models to represent the sloping, slightly irregular pads on which the piles are situated. Excluding Pile #11, the remaining pile has a percent difference value of +15.26 percent. Pile #11, which was being removed during the investigation, had a computed weight of 43,869,109.6 lb as of 14 November 1996. The difference between the computed weight and adjusted weight on record (i.e., the originally reported weight less the quantity of ore removed prior to the survey) is -19.17 percent.

All but one of the ten ore stockpiles investigated at the Belle Mead Depot, NJ, have computed pile weights less than the reported weights. In addition, six of the ten ore piles have percent difference values below or within the expected error bounds for this technique (see Table 4). The four piles outside the expected range consist of low-carbon ferrochrome (see Table 3). However, the material density values are lower than expected when comparing the computed values to those from other surveys over low-carbon ferrochrome.

It is also of interest to note similarities in density values between piles of similar ore material. The average density values of the 13 ferromanganese ore piles surveyed at Seneca Army Depot ranged from 3.388 to 3.449 g/cm^3 whereas the three piles at the Belle Mead Depot had densities ranging from 3.589 to 3.677 g/cm^3. Both sets of data are less than the average computed density of 3.903 g/cm^3 for a pile of ferromanganese surveyed at the Hammond Depot, IN, in 1995 (Sjostrom and Butler 1996). The ten ore stockpiles of low-carbon ferrochrome surveyed at the Belle Mead and Somerville Depots had computed material densities ranging from 3.033 to 3.258 g/cm^3. This density range is less than a computed value of 3.843 g/cm^3 for a pile of low-carbon ferrochrome surveyed in 1995 at the Ravenna Army Ammunition Plant, OH

(Sjostrom and Butler 1996). A total of 18 piles of high-carbon ferrochrome were surveyed at the Seneca Army Depot, Belle Mead Depot, Stockton Depot, and at the facility in Large, PA. The average bulk density values for this material had a wide range with values varying from 2.991 to 3.794 g/cm^3. Yet these values are in line with computed material densities for similar material determined at a site in Charleston, SC, in which the densities ranged from 3.085 to 3.775 g/cm^3 (Sjostrom and Berry 1997). No correlation could be found during this study relating the type of placement surface, whether natural material, asphalt, or concrete, to distinct difference values between the computed and reported weights.

4 Conclusions

The Defense National Stockpile Center (DNSC) of the Defense Logistics Agency maintains stockpiles of high-grade ores at various defense depots and storage facilities throughout the country. DNSC has a requirement to produce current weight estimates for 45 statistically selected ore piles as part of a national audit. The 45 strategic ore stockpiles selected are located at the following sites: Seneca Army Depot, New York; an unmanned storage facility, Large, Pennsylvania; Belle Mead Depot and Somerville Depot, New Jersey; and Stockton Depot, California. The pile materials are all heavy metal ores consisting of either aluminum oxide, high-carbon or low-carbon ferrochrome, or high-carbon ferromanganese.

Microgravity measurements were performed over the ore stockpiles to provide average bulk density values of the ore material. Depending on the ore pile dimensions, two to four gravity survey lines are conducted perpendicular to the strike of the pile. The measured gravity data are referenced to the base station datum for each profile by correcting for the effects due to latitude, elevation, topography, earth tides, and instrument drift. In this manner, variations in the corrected gravity values are assumed to be due solely to the ore pile material. The corrected gravity data sets are analyzed using Parasnis' method to compute a volume-averaged bulk density value for ore pile material. This method has the advantage of averaging the effect of density variations more accurately than can be done from surface or core samples. The pile density determination accuracy is estimated to be approximately ± 0.2 g/cm^3 (12.5 lb/ft^3). Ore pile volumes were computed from three-dimensional pile representations constructed from the measured elevation data and estimated to be within five percent of the actual value.

The weight of stockpiled ore is calculated by multiplying the average bulk density value and computed pile volume. The percent difference between the computed weights and the reported gross weights for each stockpile should be within ± 10 to ± 15 percent. Comparing the computed weights for each ore stockpile to the reported weights provided by DNSC, it is observed that 24 of the 45 piles surveyed are below or within the expected percent difference error range. The percent difference values for another 18 ore stockpiles range from ± 15 to ± 25 percent. Three piles have computed weights differing by greater than 25 percent of the reported values.

The highest percent differences overall were computed at the Seneca Army Depot, NY where 15 stockpiles, all underestimating the reported gross weight, have percent difference values greater than 15 percent. The higher than expected difference values are likely caused by settlement of some of the ore material below the elevation of the current ground surface. Any material below the current ground surface cannot be accounted for with the current microgravity and topographic interpretation procedures. Poor definition of some pile boundaries and bases also added errors in the weight calculations. Poor definition of the pile base was also the contributing factor to the larger than expected errors for the weights of five of the nine ferrochrome piles at the Seneca Army Depot.

Five of the eight ferrochrome piles at the unmanned storage facility in Large, PA, have computed weight estimates greater than the recorded weights. These errors are likely caused by the use of simple planar models to represent the sloping, slightly irregular pads on which the piles are situated. However, six of the eight piles still have computed weights within the 10 to 15 percent of the reported weights. At the Belle Mead Depot, NJ, all but one of the ten ore stockpiles have computed pile weights less than the reported weights. In addition, six of the ten ore piles have percent difference values below or within the expected error bounds for this technique. The ore piles surveyed at the Somerville Depot, NJ, and Stockton Depot, CA, have computed weights within 10 percent of the weights on record.

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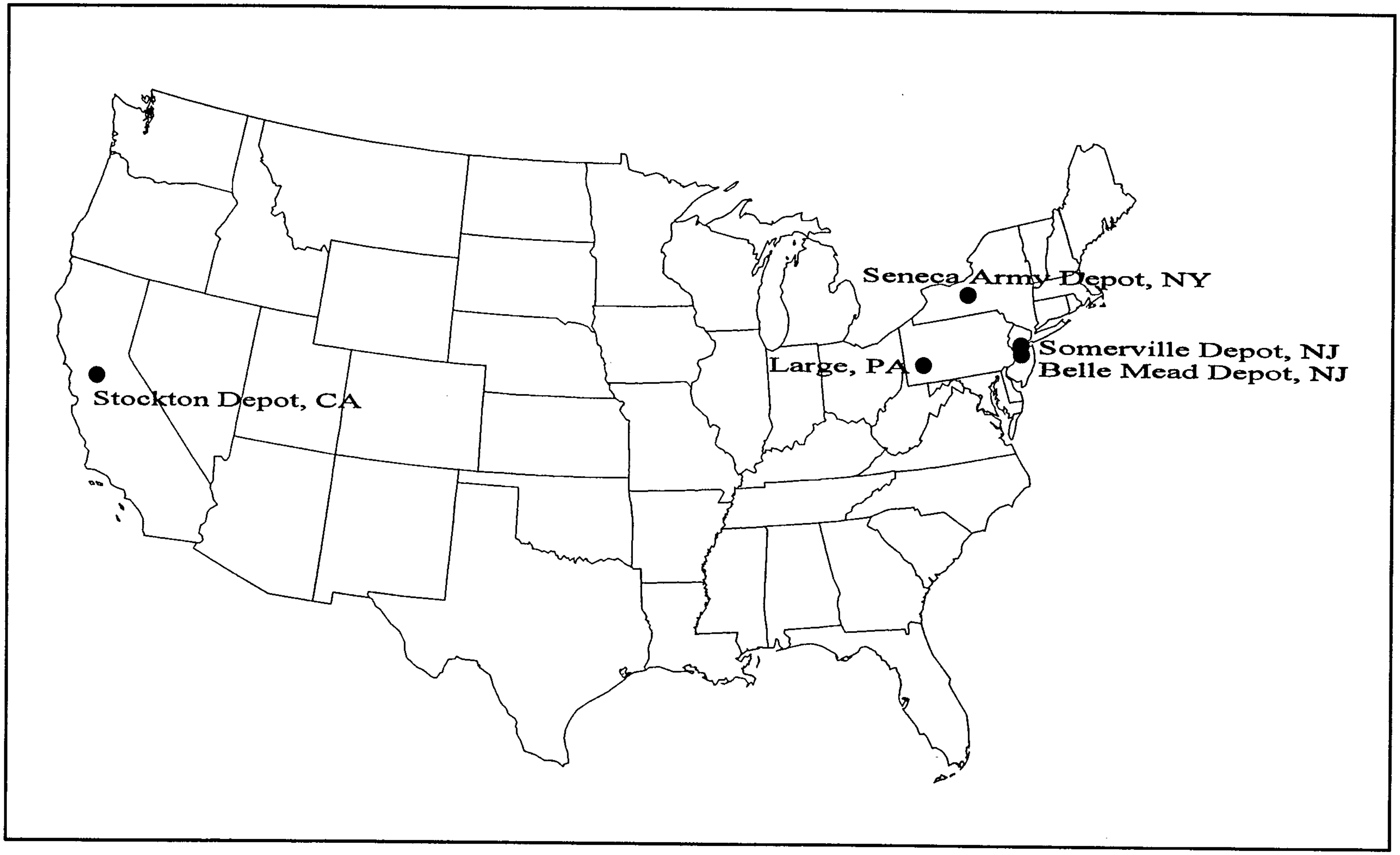


Figure 1. Location of project areas

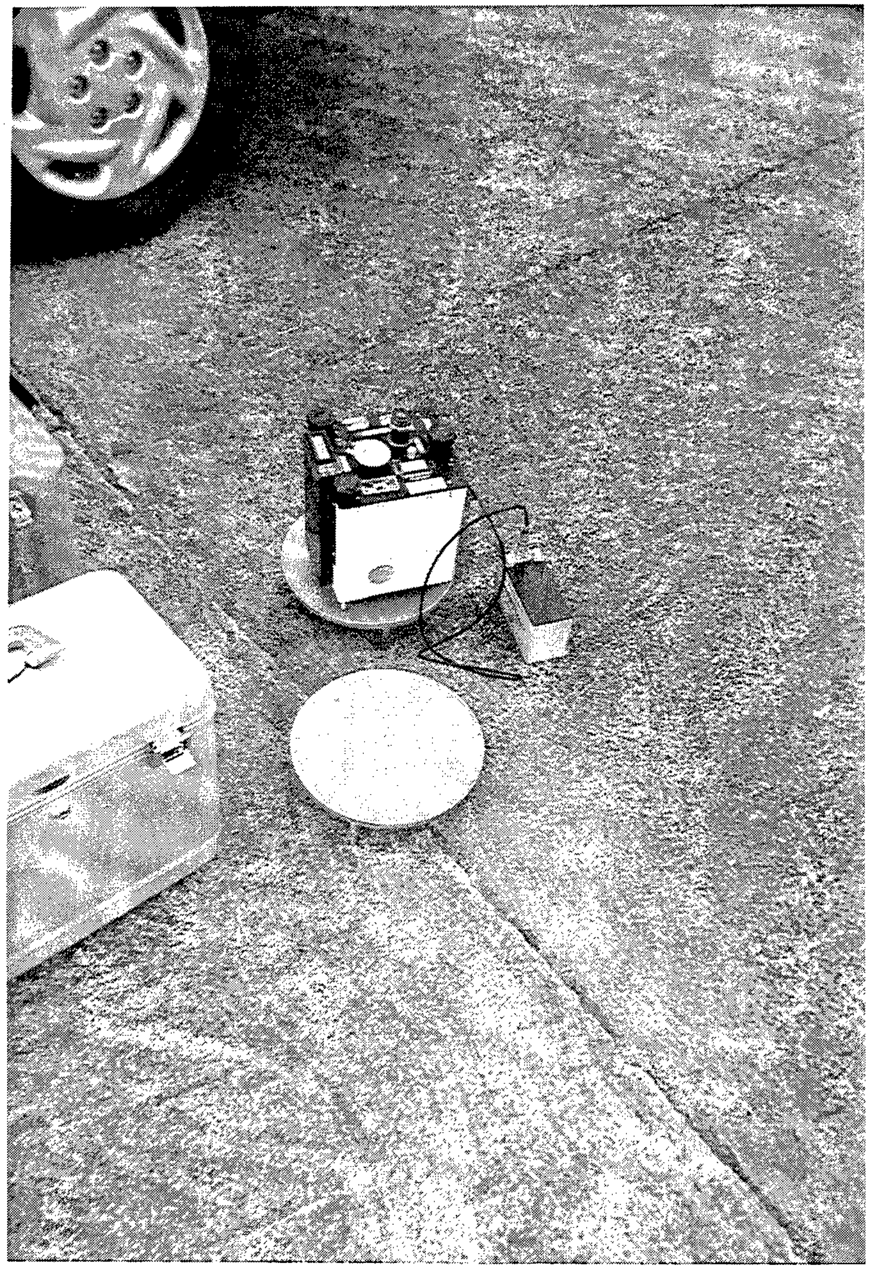


Figure 2. LaCoste and Romberg Model D gravity meter

Figure 3. Microgravity measurement stations on Pile #28, Unmanned Storage Facility, Large, PA

Figure 4. Microgravity stations located on side slope of Pile #4, Somerville Depot, NJ

Figure 5. Microgravity stations positioned on top of Pile #18, Belle Mead Depot, NJ

Figure 6. Elevation measurement at a microgravity station

Figure 7. Microgravity measurement at base station

Figure 8. Microgravity measurement on side slope of Pile #40, Seneca Army Depot, NY

Figure 9. Microgravity measurement near the top of Pile #20, Unmanned Storage Facility, Large, PA

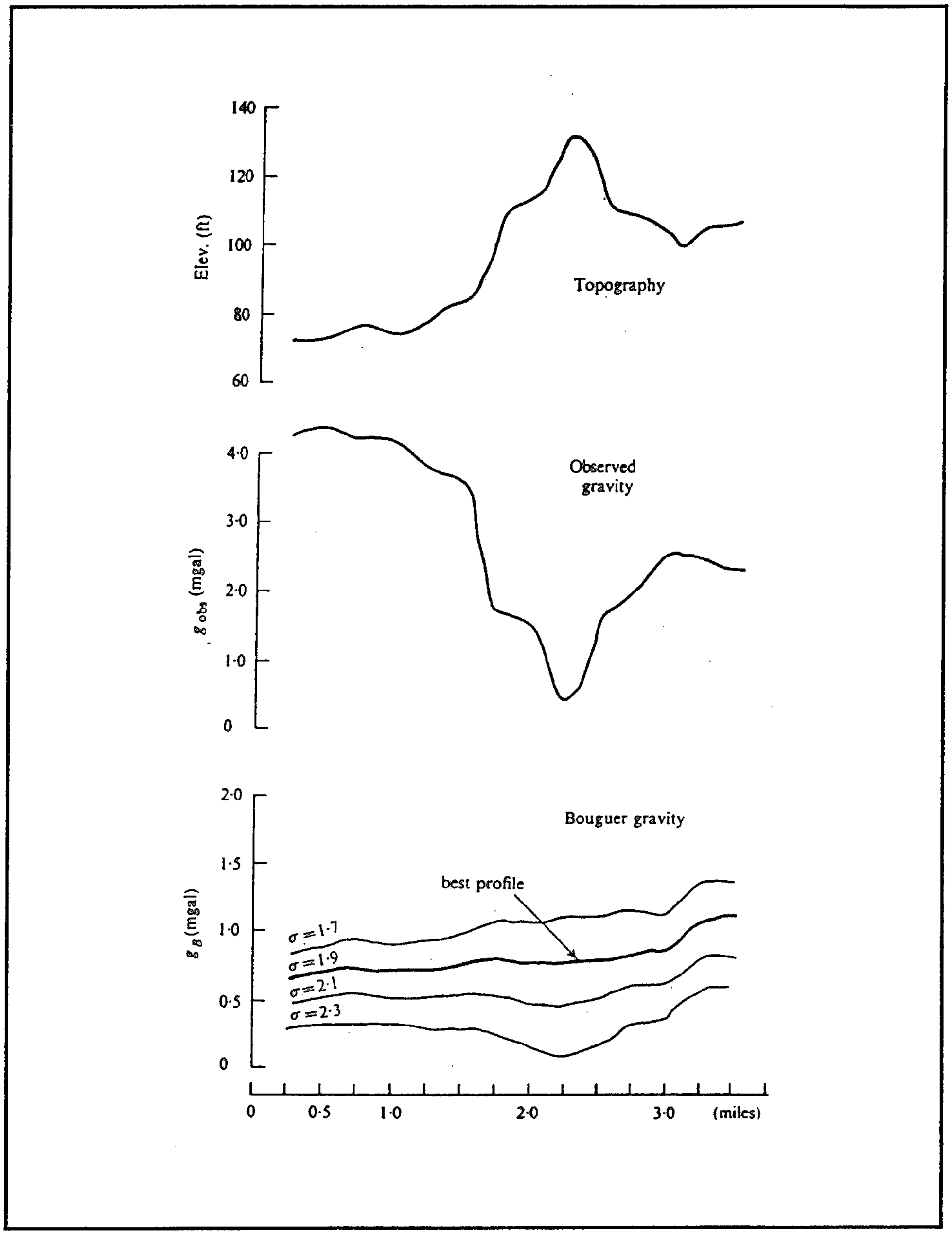


Figure 10. Application of Nettleton's method for estimating material density (Telford et al. 1990)

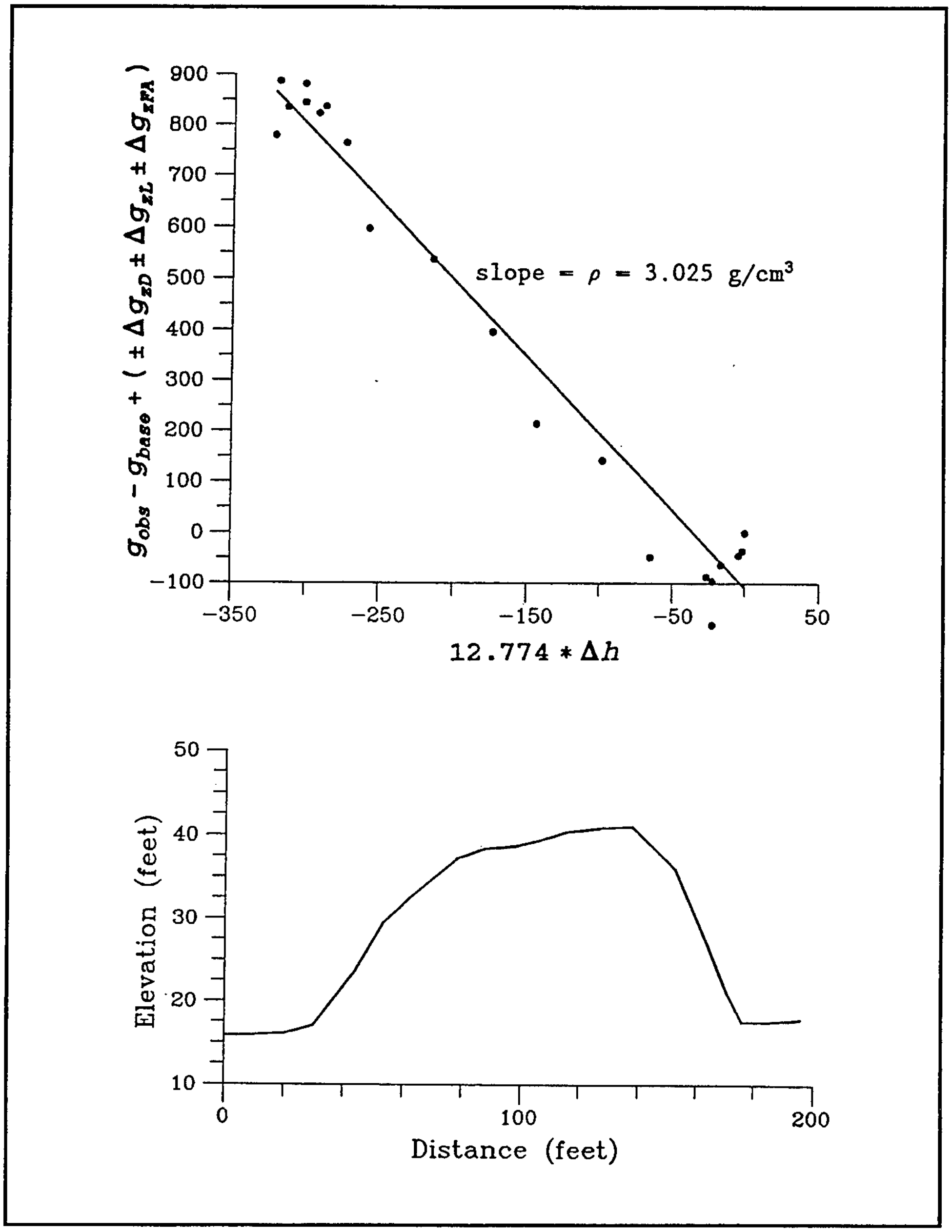


Figure 11. Application of Parasnis' method for computing material density

Table 1
Reported Description of Ore Stockpiles

Pile Number	Length, ft	Width, ft	Height, ft	Reported Gross Weight, lb	Material Description
Seneca Army Depot, NY					
40	525	100	30	110,812,140	Aluminum Oxide
43	131	100	20	29,964,520	Aluminum Oxide
18	235	74	15	30,492,620	Ferrochrome, High Carbon
19	40	35	10	1,962,550	Ferrochrome, High Carbon
20	57	45	9	3,362,725	Ferrochrome, High Carbon
25	35	30	6	568,640	Ferrochrome, High Carbon
25A	35	30	6	544, 000	Ferrochrome, High Carbon
25B	40	25	6	635,100	Ferrochrome, High Carbon
25C	27	20	6	152,600	Ferrochrome, High Carbon
25D	47	35	8	879,840	Ferrochrome, High Carbon
49	87	55	12	9,405,540	Ferrochrome, High Carbon
10	125	32	14	7,754,250	Ferromanganese, High Carbon
11	71	33	12	3,293,400	Ferromanganese, High Carbon
13	159	36	9	7,837,380	Ferromanganese, High Carbon
14	159	32	12	7,978,000	Ferromanganese, High Carbon
17	57	36	12	2,942,140	Ferromanganese, High Carbon
21	143	72	13	8,399,300	Ferromanganese, High Carbon
22	66	32	15	3,687,860	Ferromanganese, High Carbon
23	166	64	15	22,327,160	Ferromanganese, High Carbon
31	118	100	23	32,875,560	Ferromanganese, High Carbon
34	34	24	8	1,099,980	Ferromanganese, High Carbon
35	157	30	12	10,208,220	Ferromanganese, High Carbon
37	86	22	8	2,045,400	Ferromanganese, High Carbon
FM-1	280	100	25	58,600,460	Ferromanganese, High Carbon
Unmanned Storage Site, Large, PA					
11	190	125	30	63,554,860	Ferrochrome, High Carbon
12	100	150	15	32,347,540	Ferrochrome, High Carbon
20	95	50	15	8,402,100	Ferrochrome, High Carbon
24	55	115	6	3,803,230	Ferrochrome, High Carbon
25	45	25	6	563,600	Ferrochrome, High Carbon
26	50	75	10	4,911,600	Ferrochrome, High Carbon
27	35	20	4	446,300	Ferrochrome, High Carbon
28	32	35	8	1,125,820	Ferrochrome, High Carbon

(Continued)

Table 1 (Concluded)

Pile Number	Length, ft	Width, ft	Height, ft	Reported Gross Weight, lb	Material Description
Belle Mead Depot, NJ					
15	45	79	12	5,443,680	Ferrochrome, High Carbon
2	163	49	20	14,482,025	Ferrochrome, Low Carbon
3 (1 of 2)	149	49	20	17,236,526	Ferrochrome, Low Carbon
3 (2 of 2)	46	48	19		
4 (1 of 2)	35	49	20	12,434,270	Ferrochrome, Low Carbon
4 (2 of 2)	78	49	20		
5	101	49	15	9,121,120	Ferrochrome, Low Carbon
6	223	48	20	21,116,400	Ferrochrome, Low Carbon
8	108	48	25	10,953,510	Ferrochrome, Low Carbon
12	6	48	6	357,920	Ferromanganese, High Carbon
16	85	115	24	26,422,660	Ferromanganese, High Carbon
18	217	113	25	105,729,960	Ferromanganese, High Carbon
Somerville Depot, NJ					
3	100	44	16	9,183,109	Ferrochrome, Low Carbon
4	100	35	12	5,264,000	Ferrochrome, Low Carbon
Stockton Depot, CA					
1	75	35	3	1,178,760	Ferrochrome, High Carbon

Table 2
Computed Volume, Material Density, and Weight of Ore Stockpiles

Pile Number	Measured Volume, yd^3	Average Density, g/cm^3	Average Density, lb/ft^3	Average Calculated Weight, lb
Seneca Army Depot, NY				
40	30,202.5	1.925	120.17	97,997,909.8
43	7,467.9	2.125	132.66	26,748,572.8
18	4,981.2	3.178	198.40	26,682,778.9
19	340.8	2.991	186.72	1,718,142.5
20	511.7	3.096	193.28	2,670,296.9
25	81.8	3.096	193.28	426,871.8
25A	99.0	3.096	193.28	516,629.7
25B	87.7	3.096	193.28	457,660.8
25C	23.4	3.096	193.28	122,112.5
25D	147.5	3.096	193.28	769,726.0
49	1,437.9	3.024	188.78	7,329,150.8
10	1,115.4	3.388	211.51	6,369,674.3
11	511.6	3.419	213.44	2,948,307.8
13	1,105.6	3.419	213.44	6,371,479.9
14	1,094.8	3.419	213.44	6,309,240.4
17	430.6	3.419	213.44	2,481,511.6
21	1,216.4	3.419	213.44	7,010,011.0
22	474.6	3.449	215.31	2,759,078.9
23	3,276.5	3.388	211.51	18,710,989.7
31	4,880.2	3.419	213.44	28,124,182.5
34	102.6	3.419	213.44	591,275.2
35	1,454.4	3.419	213.44	8,381,585.0
37	279.9	3.419	213.44	1,613,040.2
FM-1	8,909.9	3.449	215.31	51,797,549.0
Unmanned Storage Site, Large, PA				
11	7,152.1	3.639	227.18	43,869,109.6
12	5,829.9	3.794	236.85	37,282,207.4
20	1,659.5	3.386	211.38	9,471,252.1
24	702.7	3.639	227.18	4,310,177.9
25	90.0	3.639	227.18	552,036.5
26	731.0	3.637	227.05	4,481,298.4
27	80.2	3.639	227.18	491,925.8
28	189.5	3.740	233.48	1,194,604.1

(Continued)

Table 2 (Concluded)				
Pile Number	Measured Volume, yd^3	Average Density, g/cm^3	Average Density, lb/ft^3	Average Calculated Weight, lb
Belle Mead Depot, NJ				
15	886.2	3.211	200.46	4,796,398.3
2	2,467.5	3.128	195.27	13,009,694.3
3 (1 of 2)	2,281.4	3.211	200.46	12,347,667.6
3 (2 of 2)	401.6	3.128	195.27	2,117,403.5
4 (1 of 2)	944.9	3.128	195.27	4,981,908.9
4 (2 of 2)	100.4	3.128	195.27	5,344,124.1
5	1,441.9	3.139	195.96	7,629,035.6
6	3,706.1	3.128	195.27	19,540,112.7
8	1,677.7	3.033	189.34	8,576,891.2
12	60.4	3.633	226.80	369,867.0
16	3,945.9	3.589	224.05	23,870,566.1
18	15,479.3	3.677	229.55	95,937,441.6
Somerville Depot, NJ				
3	1,547.7	3.258	203.39	8,499,258.7
4	1,060.5	3.258	203.39	5,823,779.7
Stockton Depot, CA				
1	180.5	3.518	219.62	1,070,326.4

Table 3
Comparison of Reported and Computed Ore Pile Weights

Pile Number	Reported Gross Weight, lbs	Average Calculated Weight, lbs	Percent Difference
Seneca Army Depot, NY			
40	110,812,140	97,997,909.8	-11.56
43	29,964,520	26,748,572.8	-10.73
18	30,492,620	26,682,778.9	-12.49
19	1,962,550	1,718,142.5	-12.45
20	3,362,725	2,670,296.9	-20.59
25	568,640	426,871.8	-24.93
25A	544, 000	516,629.7	-5.03
25B	635,100	457,660.8	-27.94
25C	152,600	122,112.5	-19.98
25D	879,840	769,726.0	-12.52
49	9,405,540	7,329,150.8	-22.08
10	7,754,250	6,369,674.3	-17.86
11	3,293,400	2,948,307.8	-10.48
13	7,837,380	6,371,479.9	-18.70
14	7,978,000	6,309,240.4	-20.92
17	2,942,140	2,481,511.6	-15.66
21	8,399,300	7,010,011.0	-16.54
22	3,687,860	2,759,078.9	-25.18
23	22,327,160	18,710,989.7	-16.20
31	32,875;560	28,124,182.5	-14.45
34	1,099,980	591,275.2	-46.25
35	10,208,220	8,381,585.0	-17.89
37	2,045,400	1,613,040.2	-21.14
FM-1	58,600,460	51,797,549.0	-11.61
Unmanned Storage Site, Large, PA			
11	63,554,860[1] 54,274,840[2]	43,869,109.6	-19.17
12	32,347,540	37,282,207.4	+15.26
20	8,402,100	9,471,252.1	+12.72
24	3,803,230	4,310,177.9	+13.33
25	563,600	552,036.5	-2.05
26	4,911,600	4,481,298.4	-8.76
27	446,300	491,925.8	+10.22
28	1,125,820	1,194,604.1	+6.11

(Continued)

[1] Originally reported weight.
[2] Weight as of 14 November 1996 when the volume determination was made. Pile #11 was being removed during the investigation.

Table 3 (Concluded)			
Pile Number	Reported Gross Weight, lbs	Average Calculated Weight, lbs	Percent Difference
Belle Mead Depot, NJ			
15	5,443,680	4,796,398.3	-11.89
2	14,482,025	13,009,694.3	-10.17
3 (1 of 2)	17,236,526	14,465,071.1	-16.08
3 (2 of 2)			
4 (1 of 2)	12,434,270	10,326,032.9	-16.96
4 (2 of 2)			
5	9,121,120	7,629,035.6	-16.36
6	21,116,400	19,540,112.7	-7.46
8	10,953,510	8,576,891.2	-21.70
12	357,920	369,867.0	+3.34
16	26,422,660	23,870,566.1	-9.66
18	105,729,960	95,937,441.6	-9.26
Somerville Depot, NJ			
3	9,183,109	8,499,258.7	-7.45
4	5,264,000	5,823,779.7	+10.63
Stockton Depot, CA			
1	1,178,760	1,070,326.4	-9.20

Table 4
Distribution of Stockpiles Versus Percent Difference Ranges

	Percent Difference Range	Number of Ore Stockpiles: Seneca Army Depot, NY	Large, PA	Belle Mead Depot, NJ	Somerville Depot, NJ	Stockton Depot, CA	Total	Expected Error Range Description
Calculated Weight Greater Than Reported Weight	> +40%	-	-	-	-	-	-	Well Outside
	+25% to +40%	-	-	-	-	-	-	
	+15% to +25%	-	1	-	-	-	1	Outside
	+10% to +15%	-	3	-	1	-	4	Within
	0% to +10%	-	1	1	-	-	2	Below
Calculated Weight Less Than Reported Weight	0% to -10%	1	2	3	1	1	8	
	-10% to -15%	8	-	2	-	-	10	Within
	-15% to -25%	12	1[1]	4	-	-	17	Outside
	-25% to -40%	2	-	-	-	-	2	Well Outside
	< -40%	1	-	-	-	-	1	
Total		24	8	10[2]	2	1	45[2]	

[1] Pile #11 at Large, PA was being removed during the gravity investigation.
[2] At the Belle Mead Depot, Pile #3 is divided into the separate piles labeled #3 (1 of 2) and #3 (2 of 2). Likewise, Pile #4 is subdivided into Piles #4 (1 of 2) and #4 (2 of 2).

Appendix A
Ore Pile Elevation Contour Plots and Photographs, Seneca Army Depot, NY

Aluminum Oxide

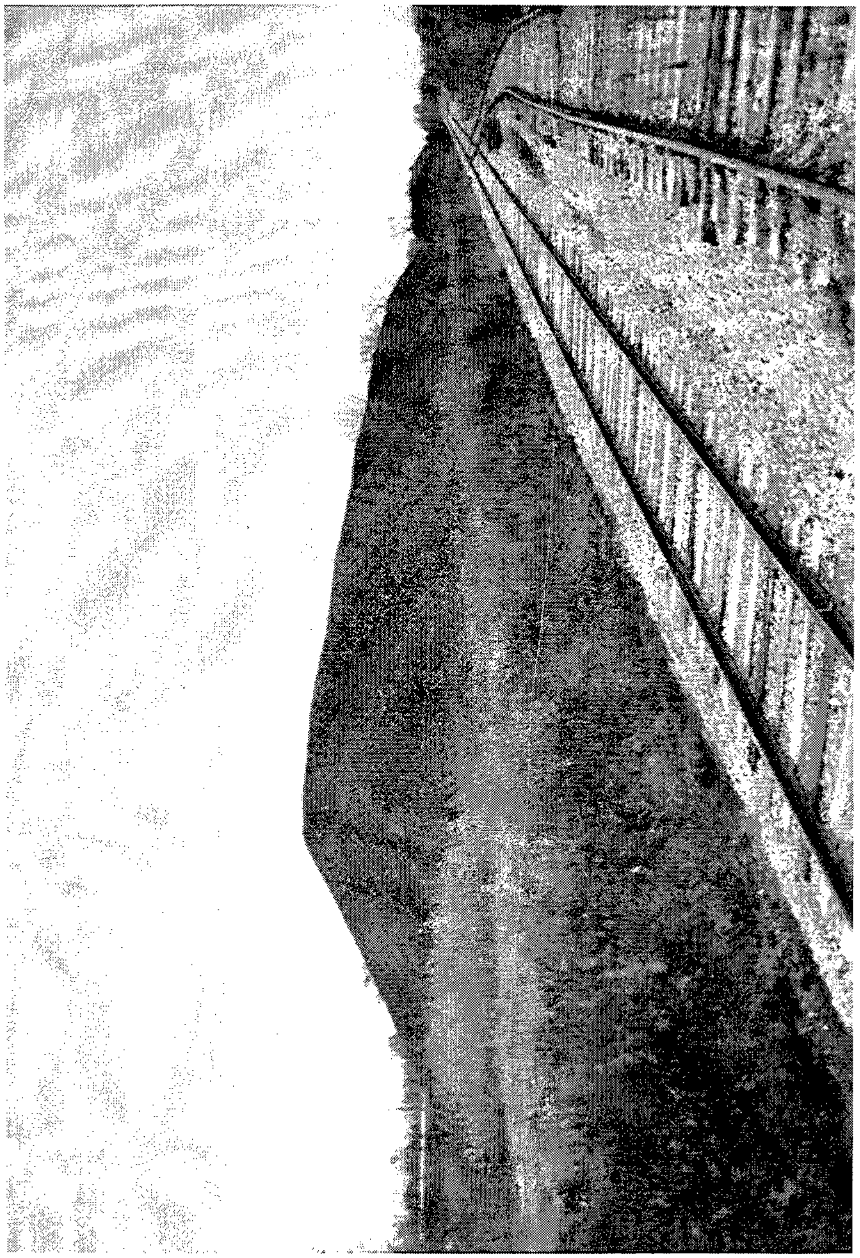


Figure A-1. Pile #40, Seneca Army Depot, NY

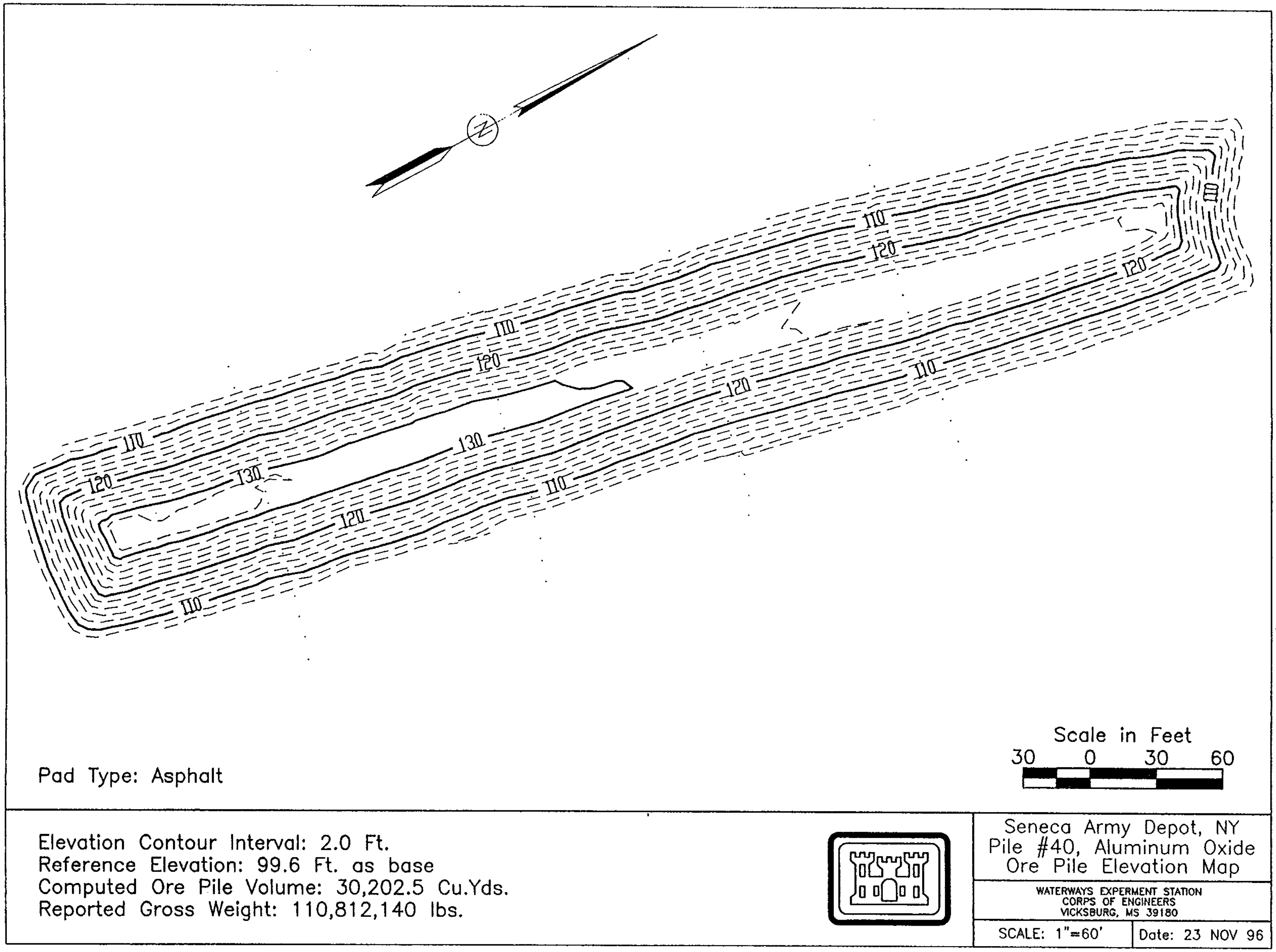


Figure A-2. Elevation contour plot of Pile #40, Seneca Army Depot, NY

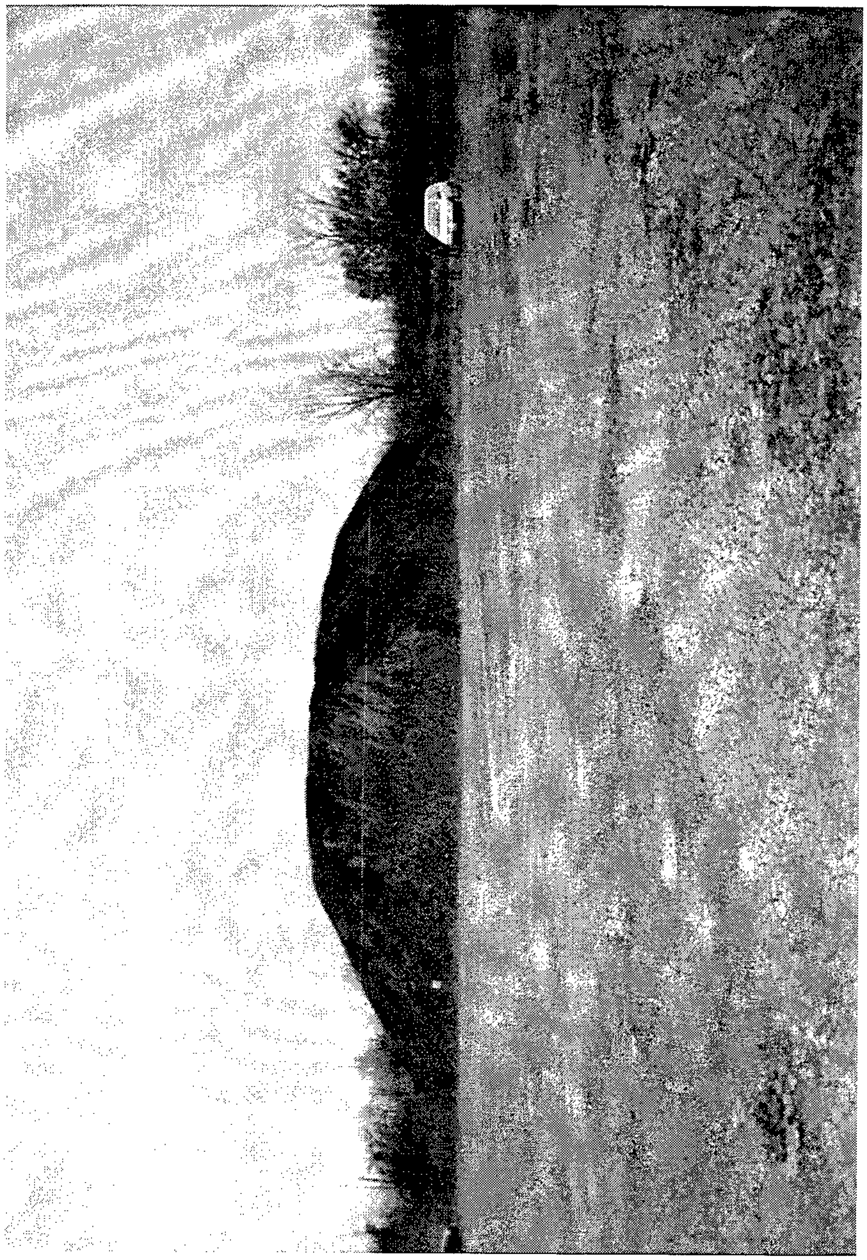


Figure A-3. View of northeast corner of Pile #43, Seneca Army Depot, NY

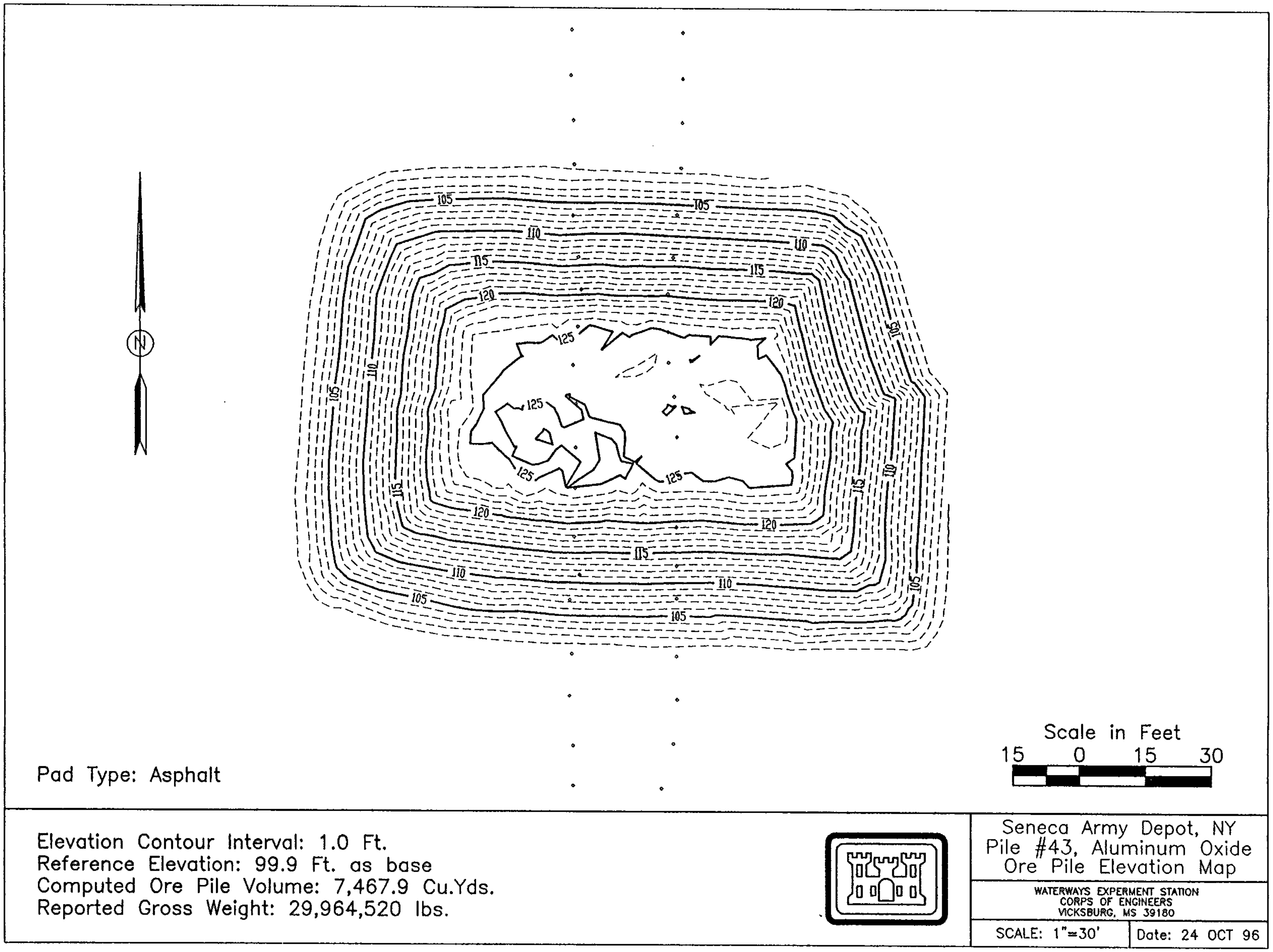


Figure A-4. Elevation contour plot of Pile #43, Seneca Army Depot, NY

High-Carbon Ferrochrome

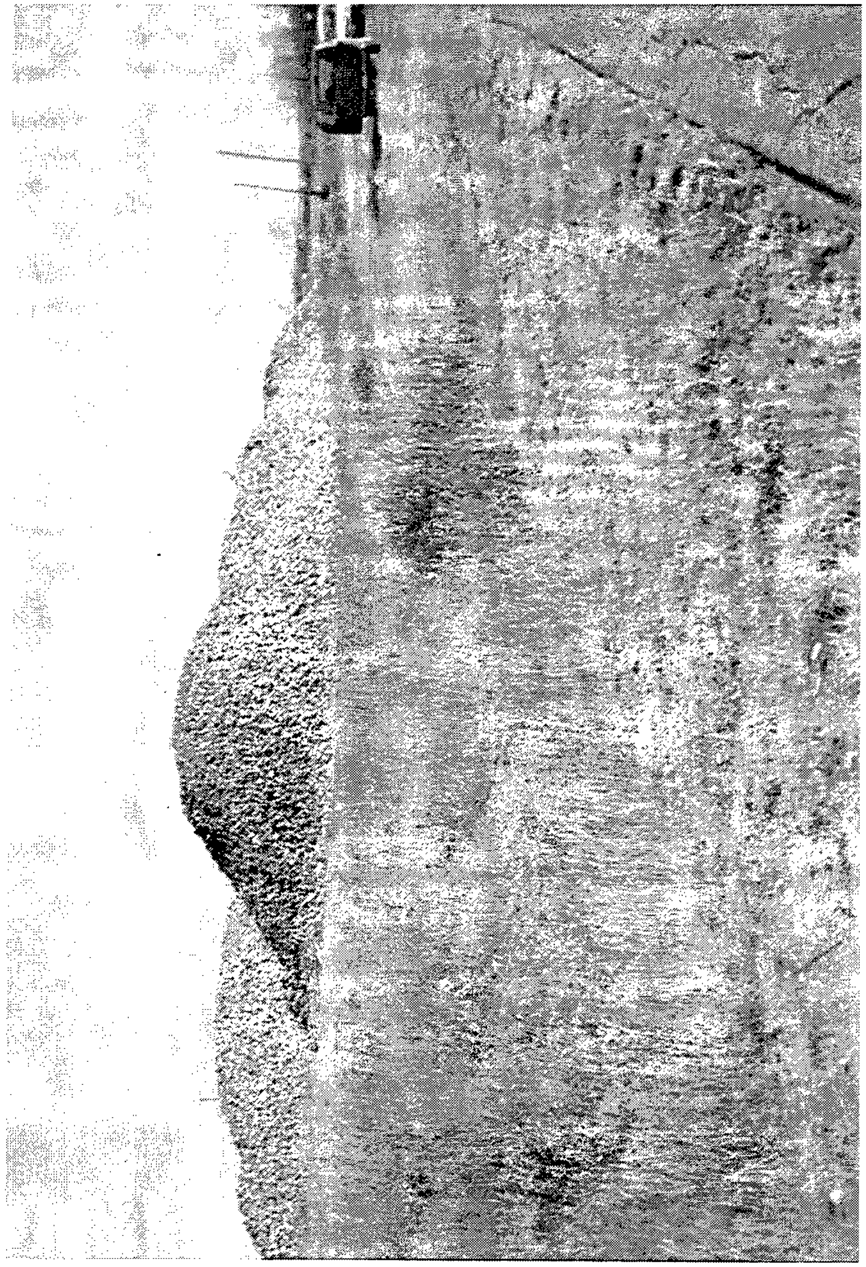


Figure A-5. Piles #18 and #49 (left), Seneca Army Depot, NY

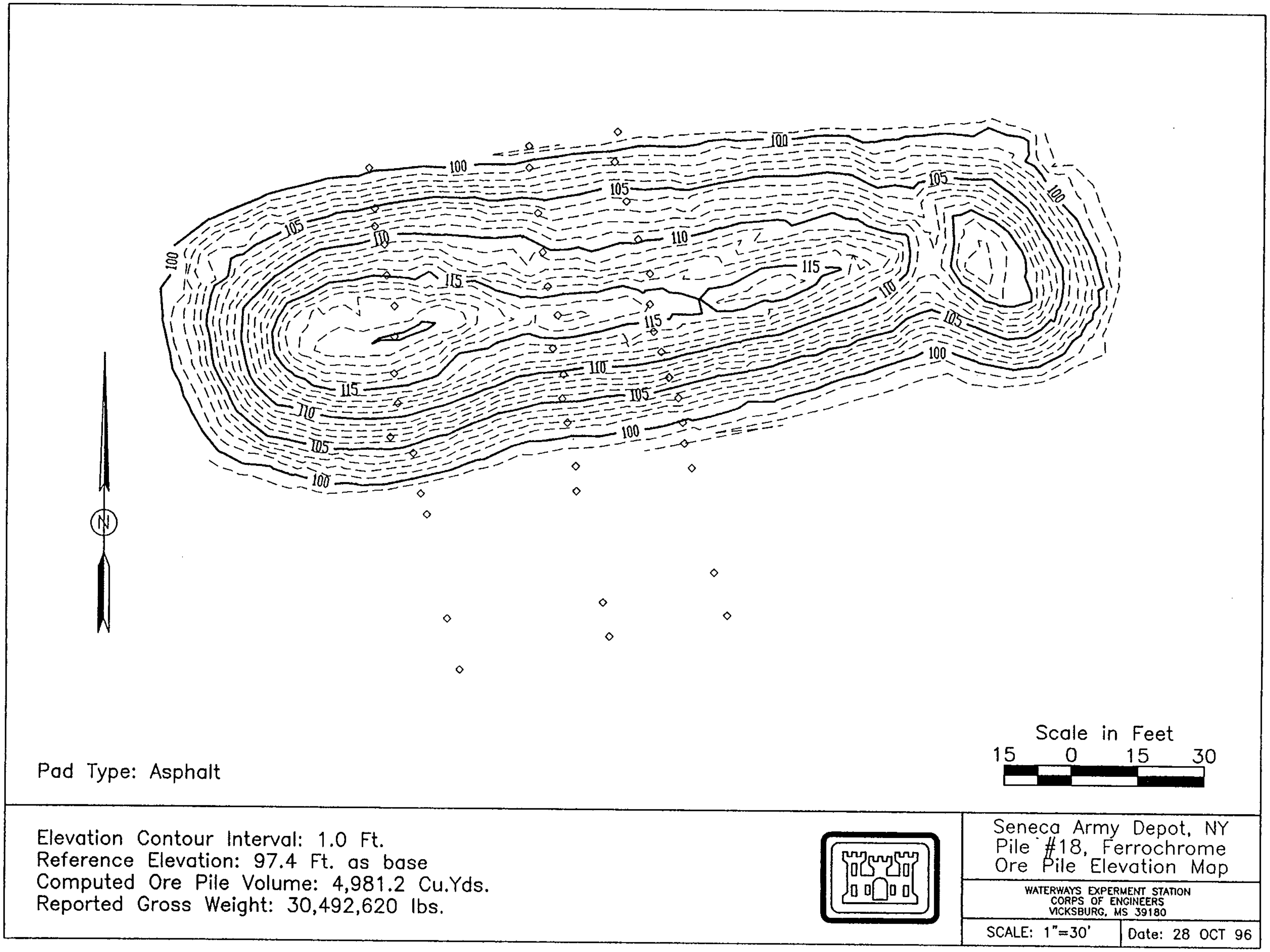


Figure A-6. Elevation contour plot of Pile #18, Seneca Army Depot, NY

Figure A-7. Piles #19 (center) and #25-D (left), Seneca Army Depot, NY

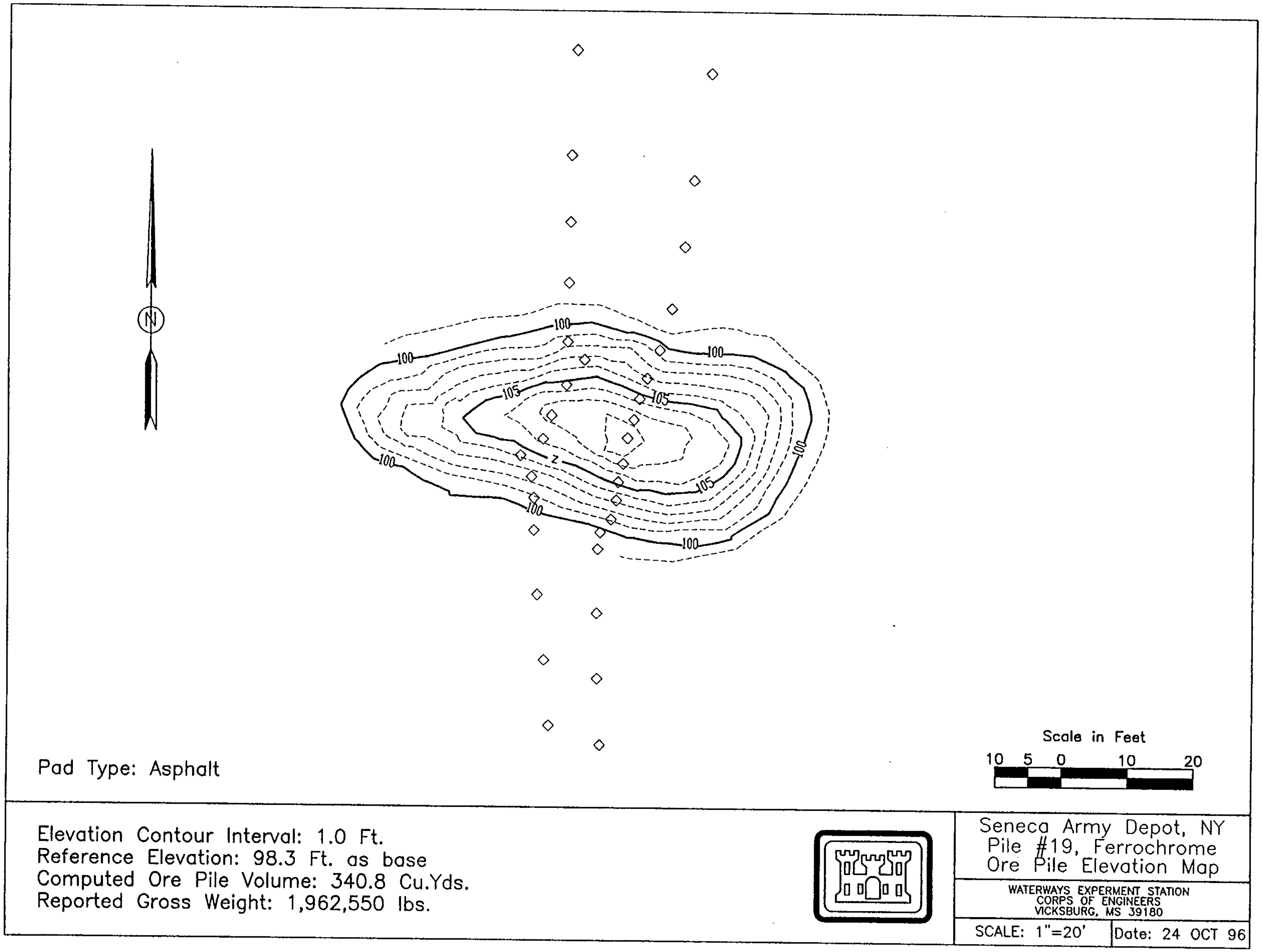


Figure A-8. Elevation contour plot of Pile #19, Seneca Army Depot, NY

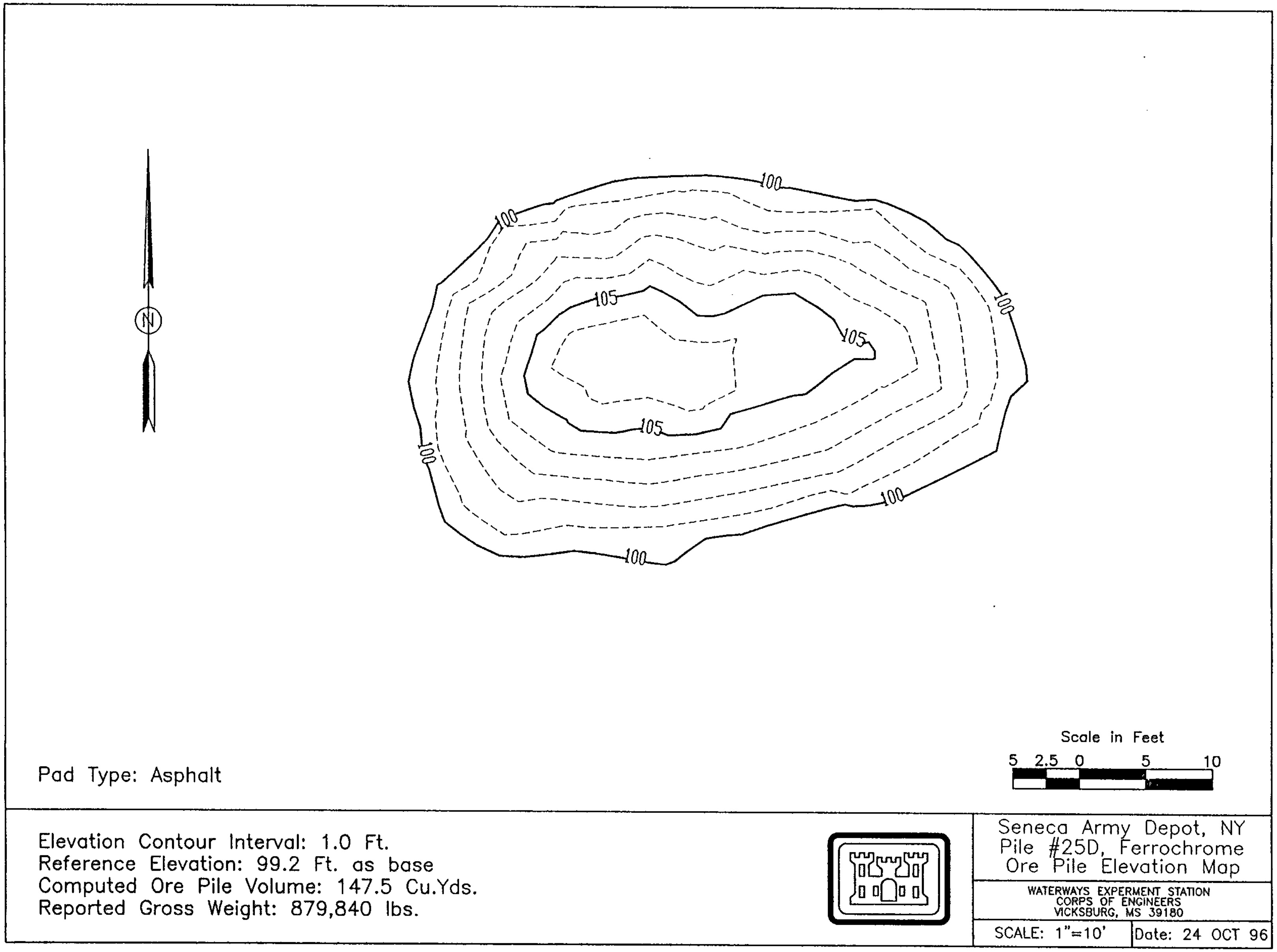


Figure A-9. Elevation contour plot of Pile #25-D, Seneca Army Depot, NY

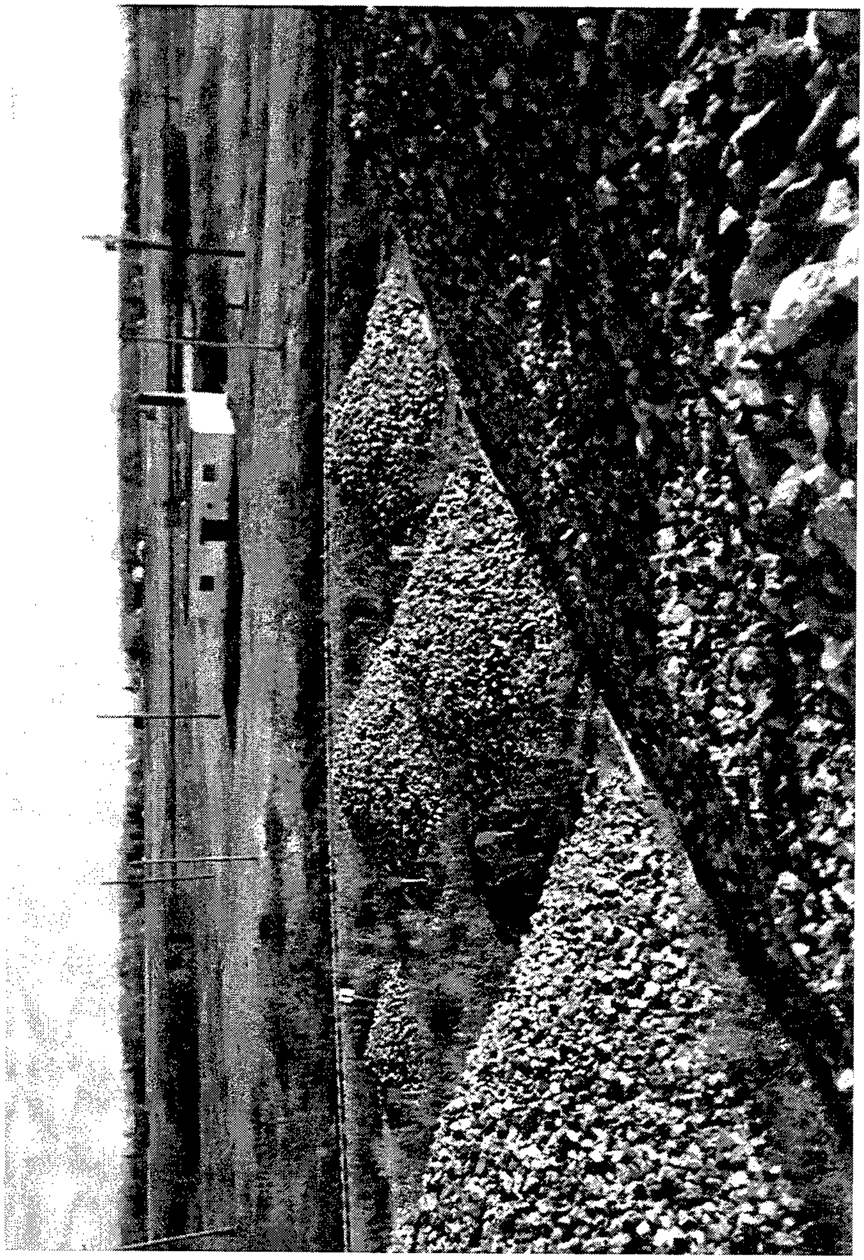


Figure A-10. Piles #25-C (back left), #25-B (back center), #25-A (back right), and #25 (center), Seneca Army Depot, NY

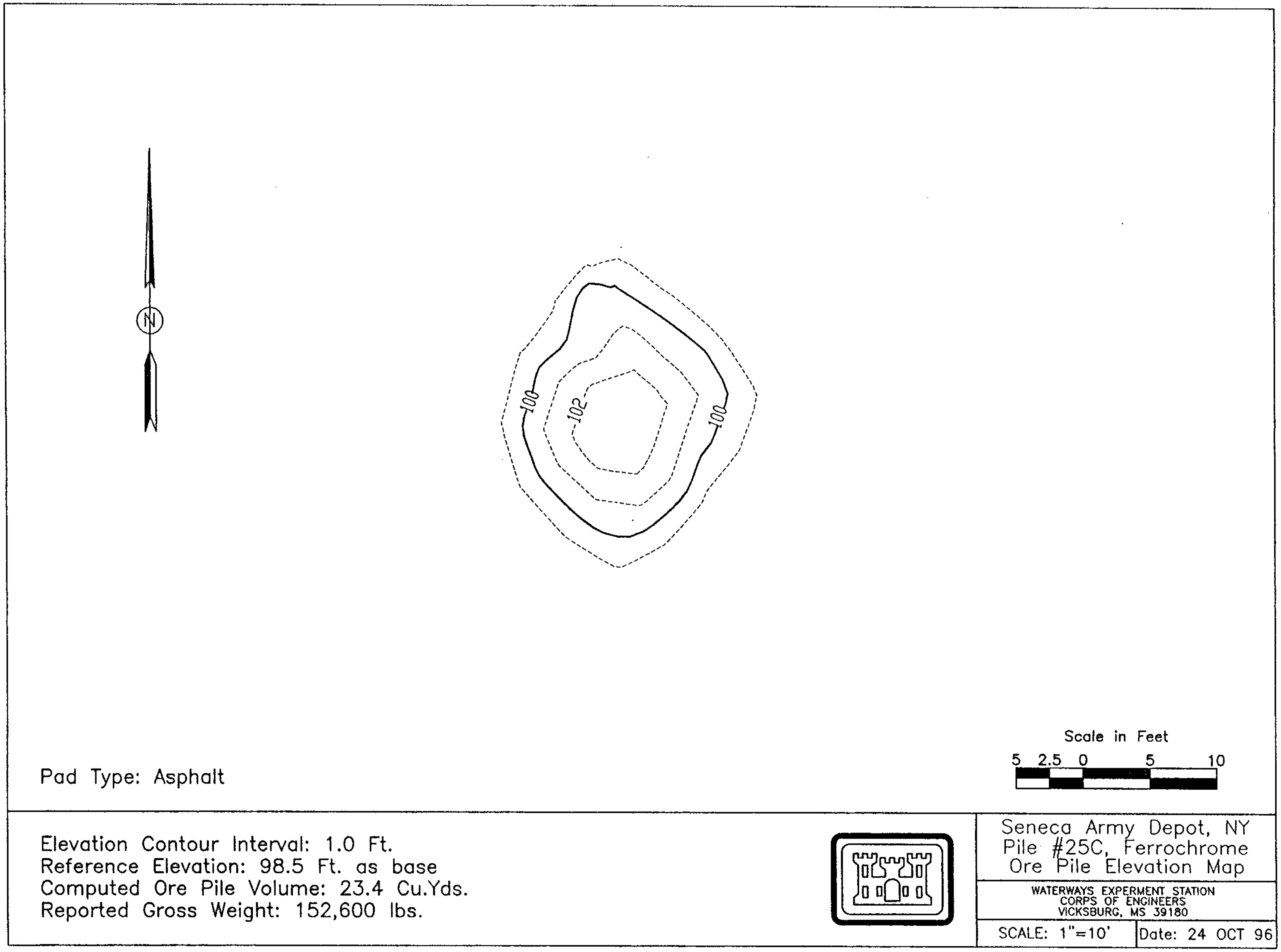


Figure A-11. Elevation contour plot of Pile #25-C, Seneca Army Depot, NY

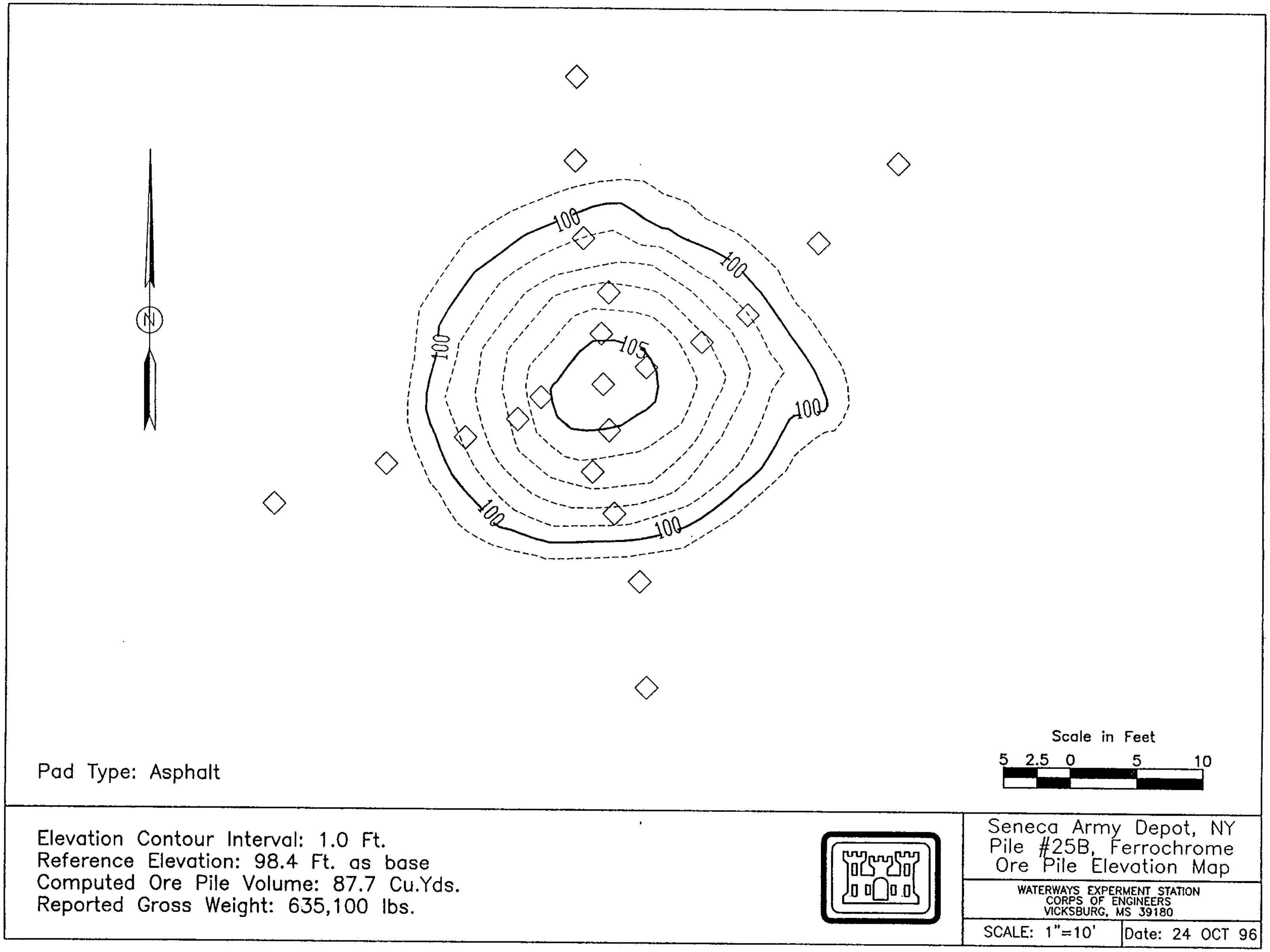
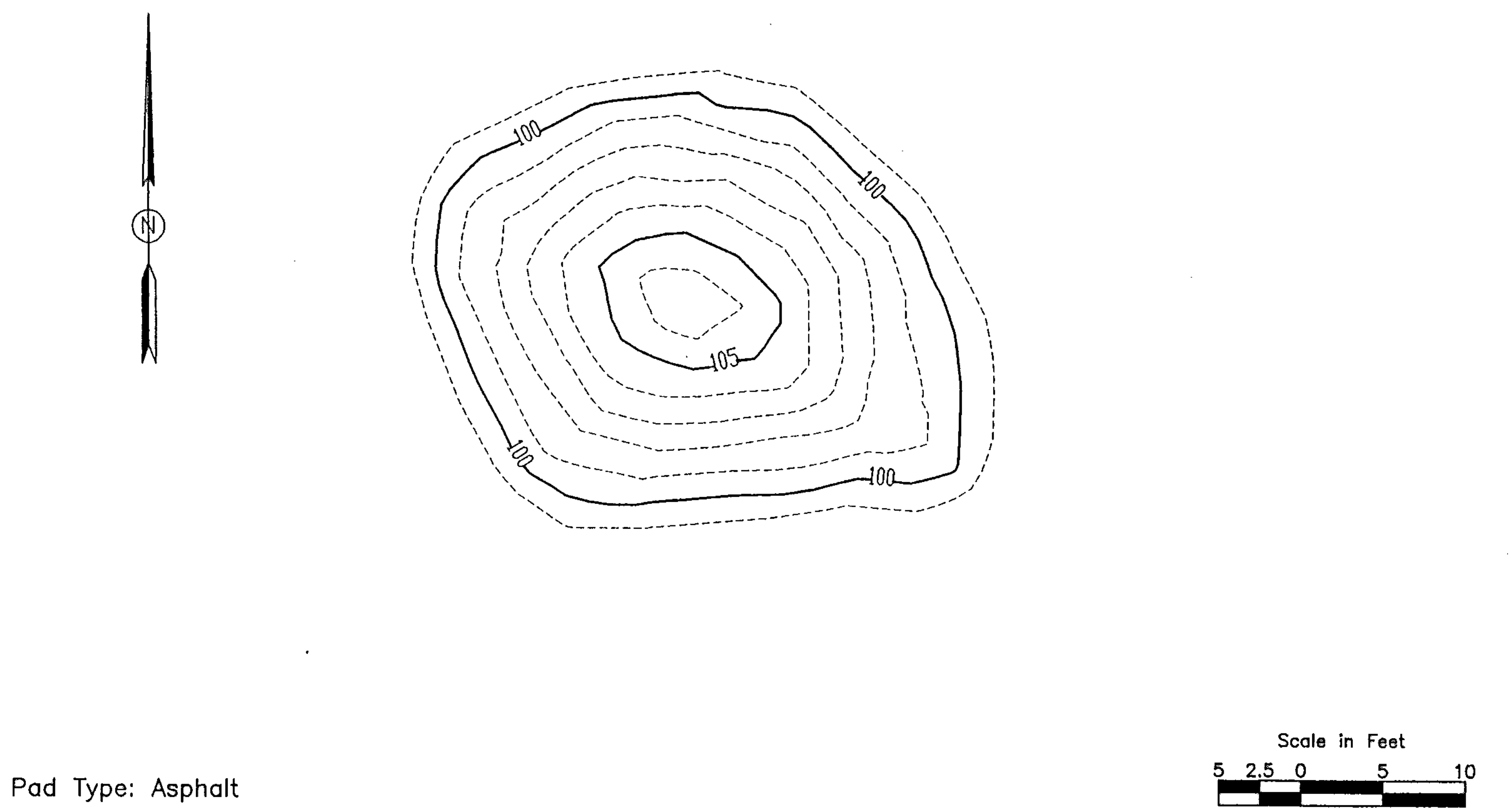


Figure A-12. Elevation contour plot of Pile #25-B, Seneca Army Depot, NY



Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 98.5 Ft. as base
Computed Ore Pile Volume: 99.0 Cu.Yds.
Reported Gross Weight: 544,000 lbs.

Seneca Army Depot, NY
Pile #25A, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=10' | Date: 24 OCT 96

Figure A-13. Elevation contour plot of Pile #25-A, Seneca Army Depot, NY

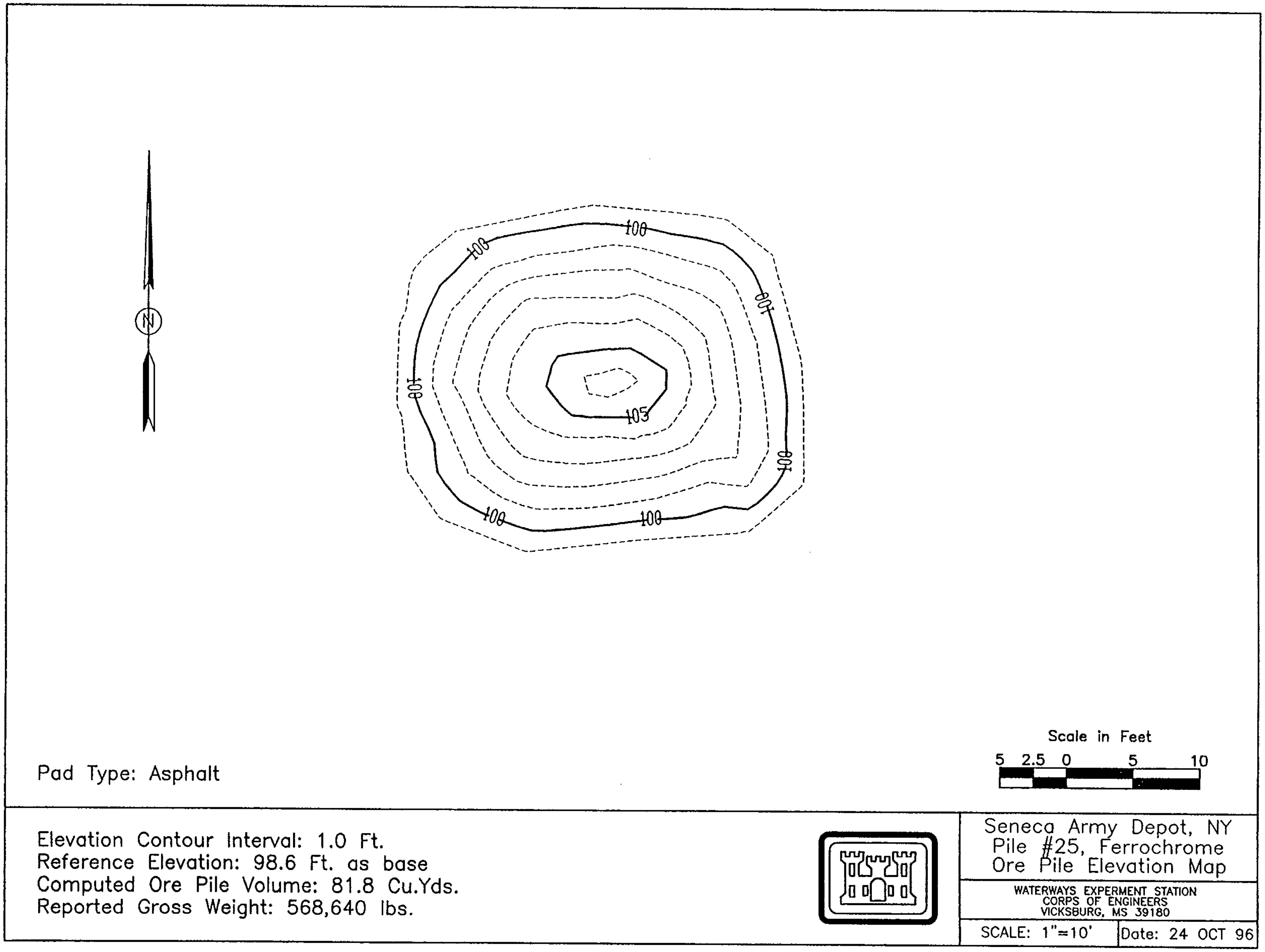


Figure A-14. Elevation contour plot of Pile #25, Seneca Army Depot, NY

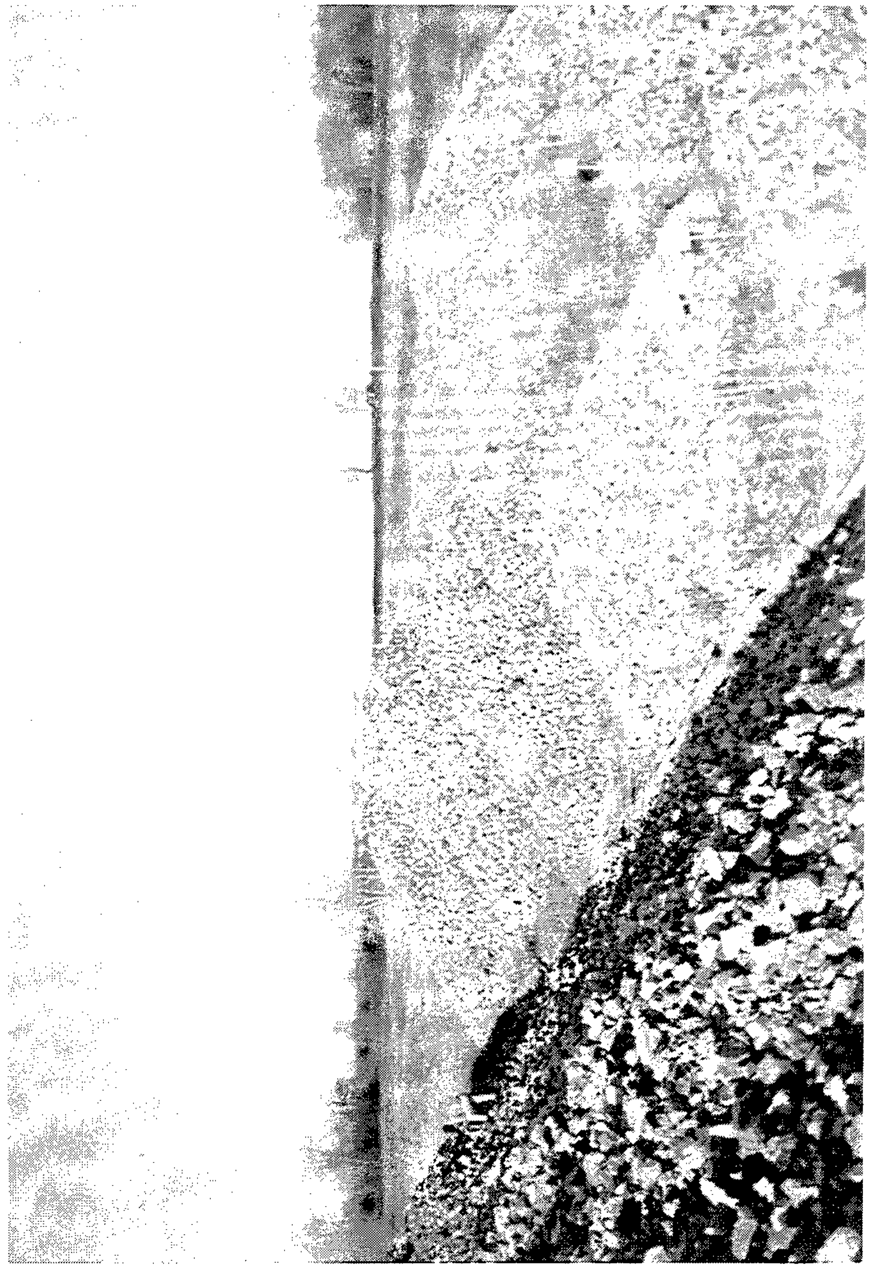


Figure A-15. Piles #49 (left), #20 (right), and #25 (center), Seneca Army Depot, NY

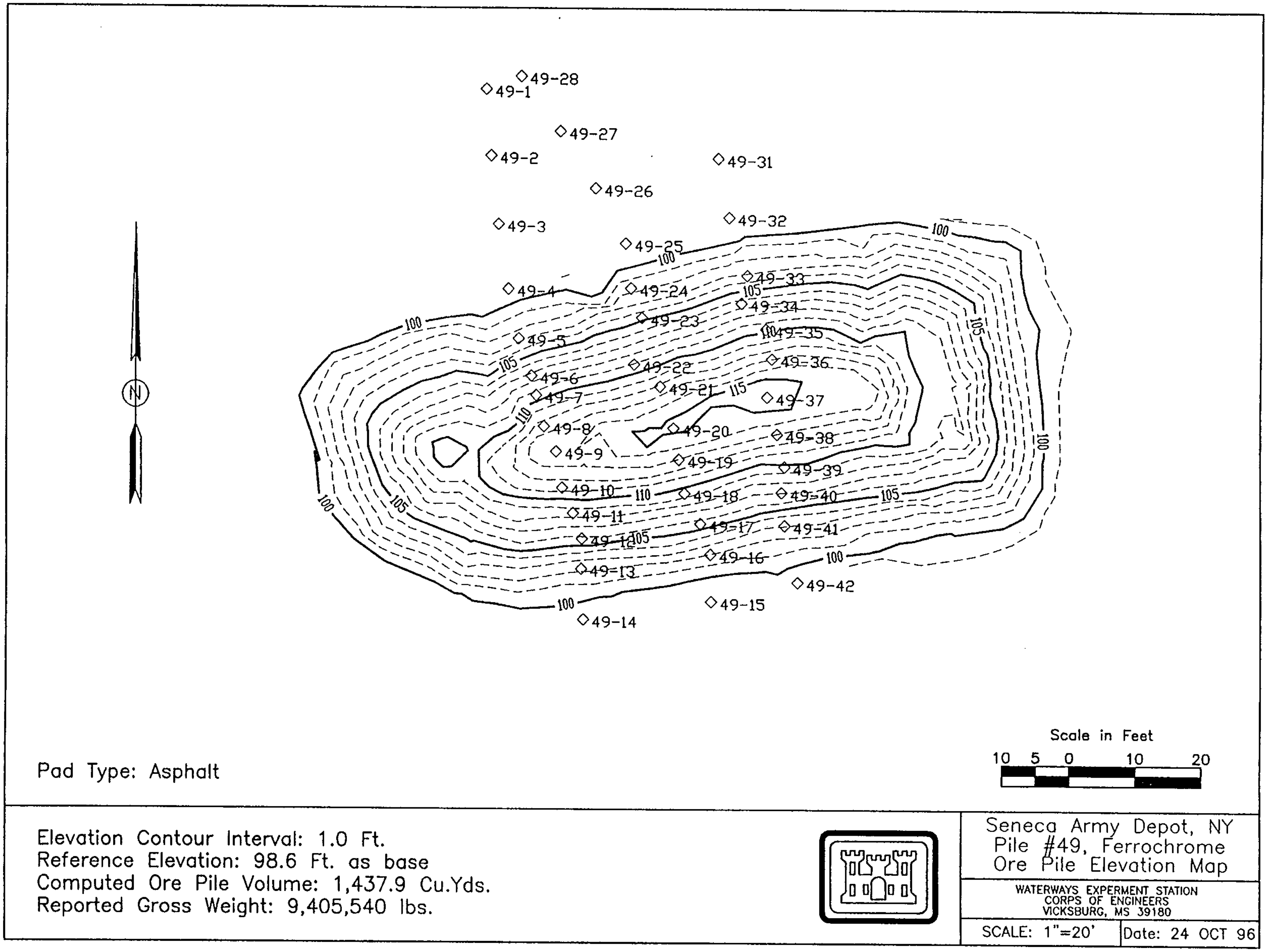


Figure A-16. Elevation contour plot of Pile #49, Seneca Army Depot, NY

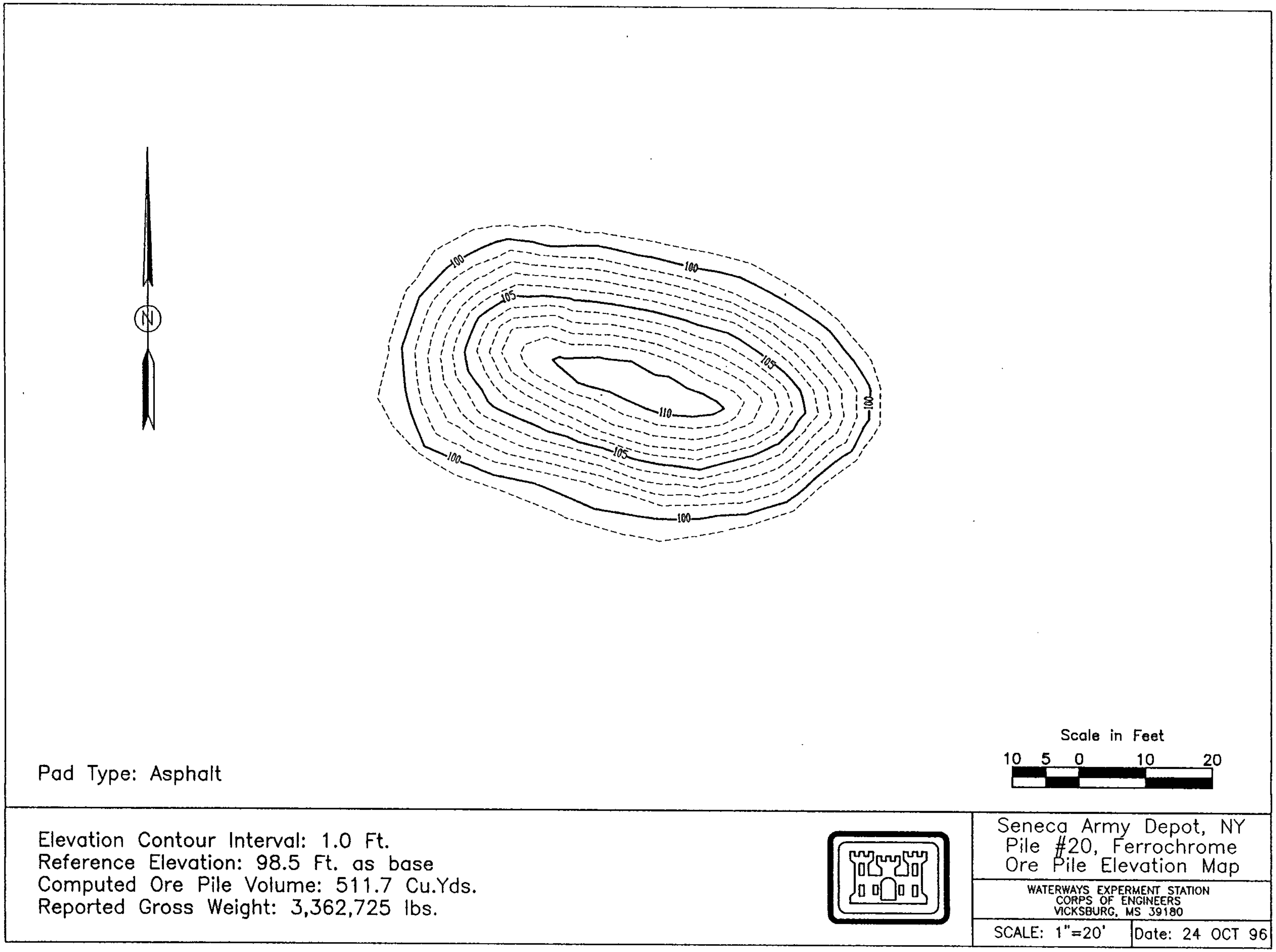


Figure A-17. Elevation contour plot of Pile #20, Seneca Army Depot, NY

High-Carbon Ferromanganese

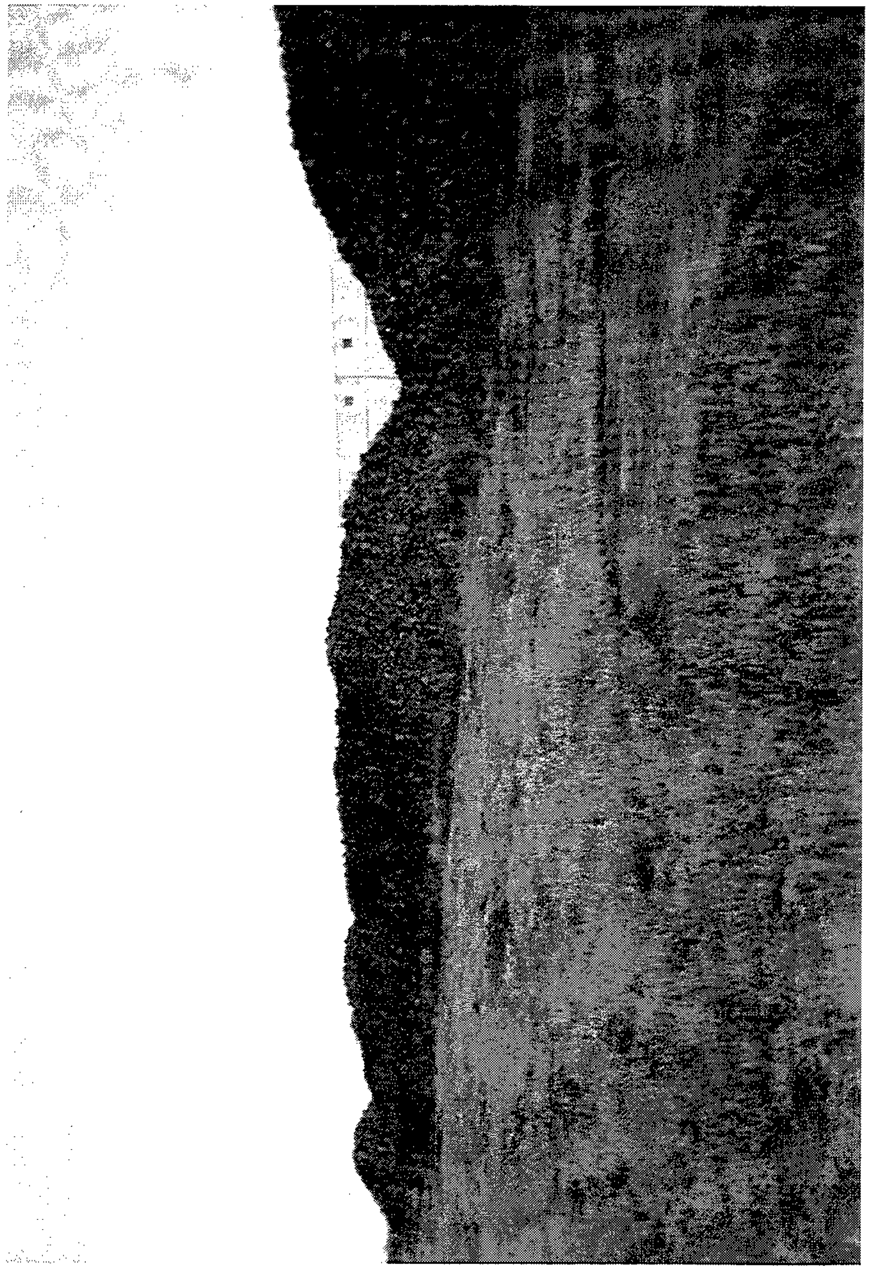


Figure A-18. Pile #13 and north end of Pile #35, Seneca Army Depot, NY

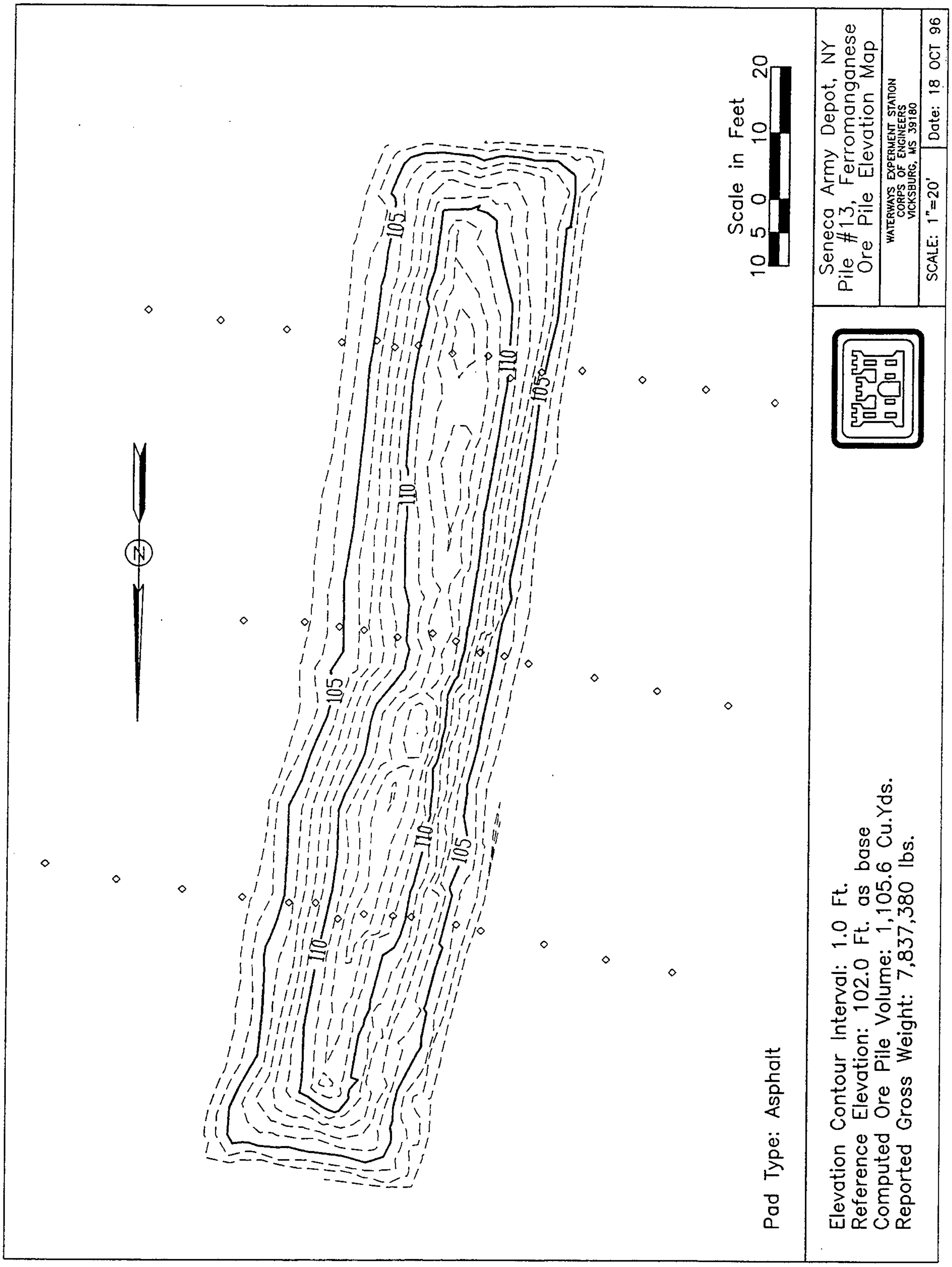


Figure A-19. Elevation contour plot of Pile #13, Seneca Army Depot, NY

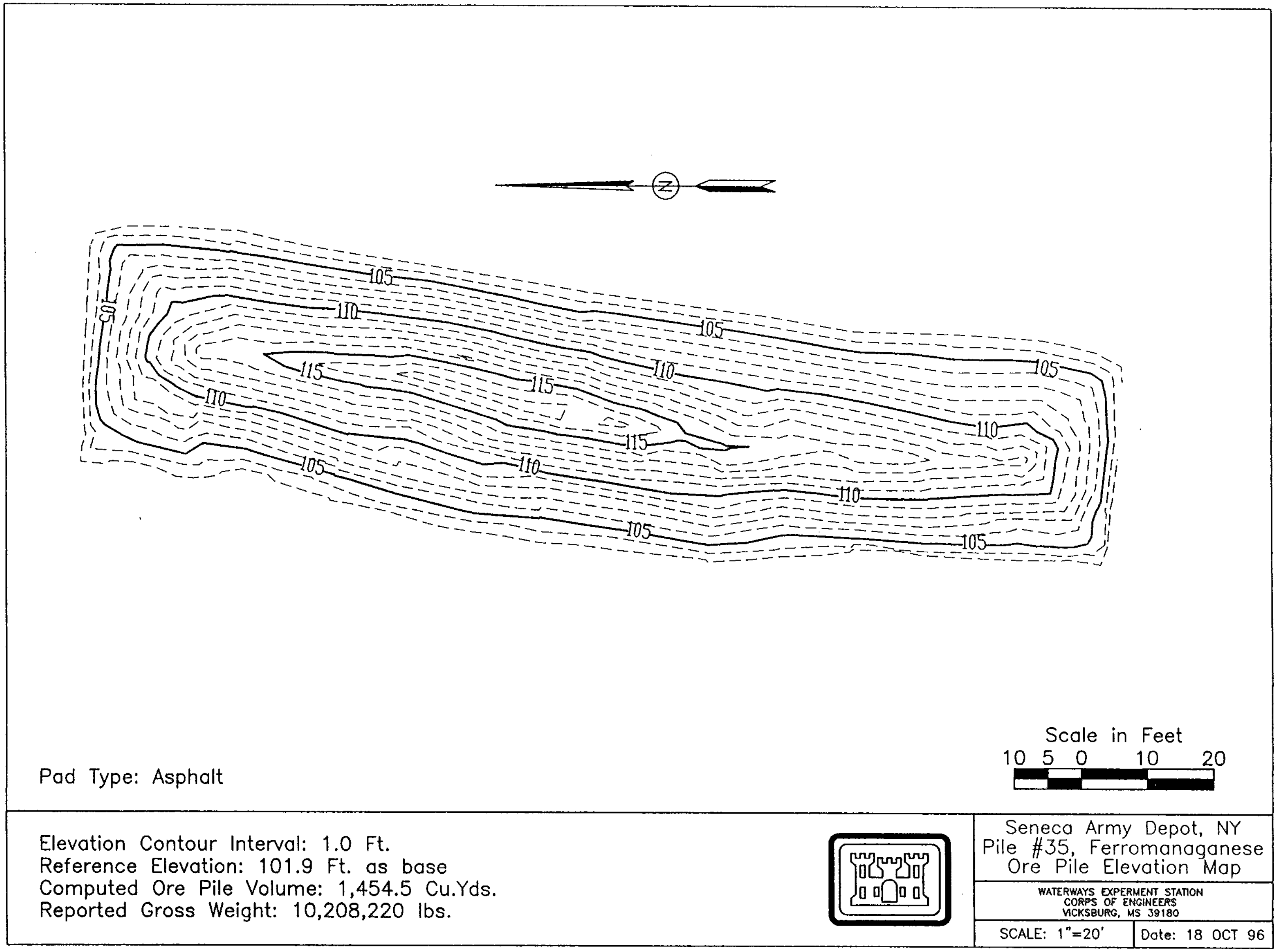


Figure A-20. Elevation contour plot of Pile #35, Seneca Army Depot, NY

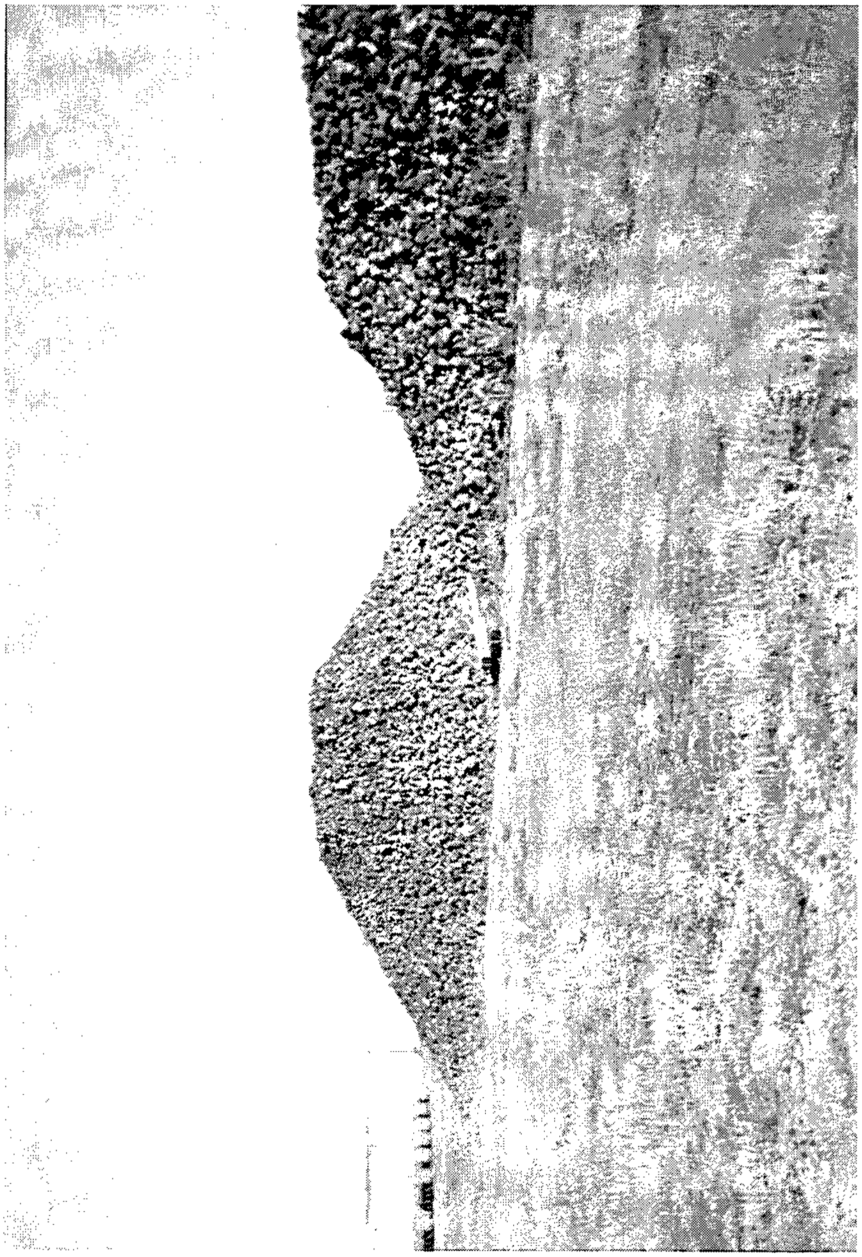


Figure A-21. Pile #17, Seneca Army Depot, NY

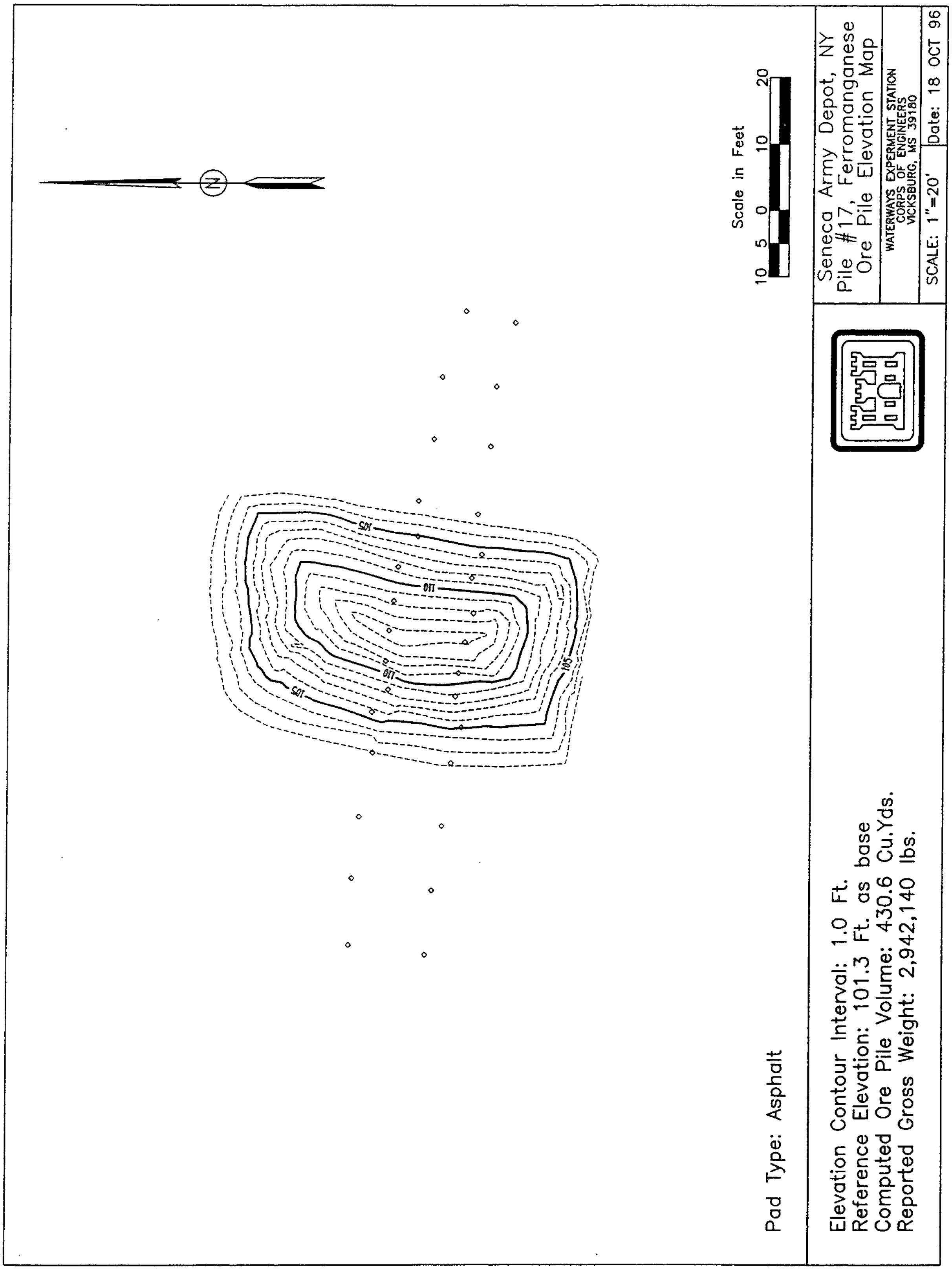


Figure A-22. Elevation contour plot of Pile #17, Seneca Army Depot, NY

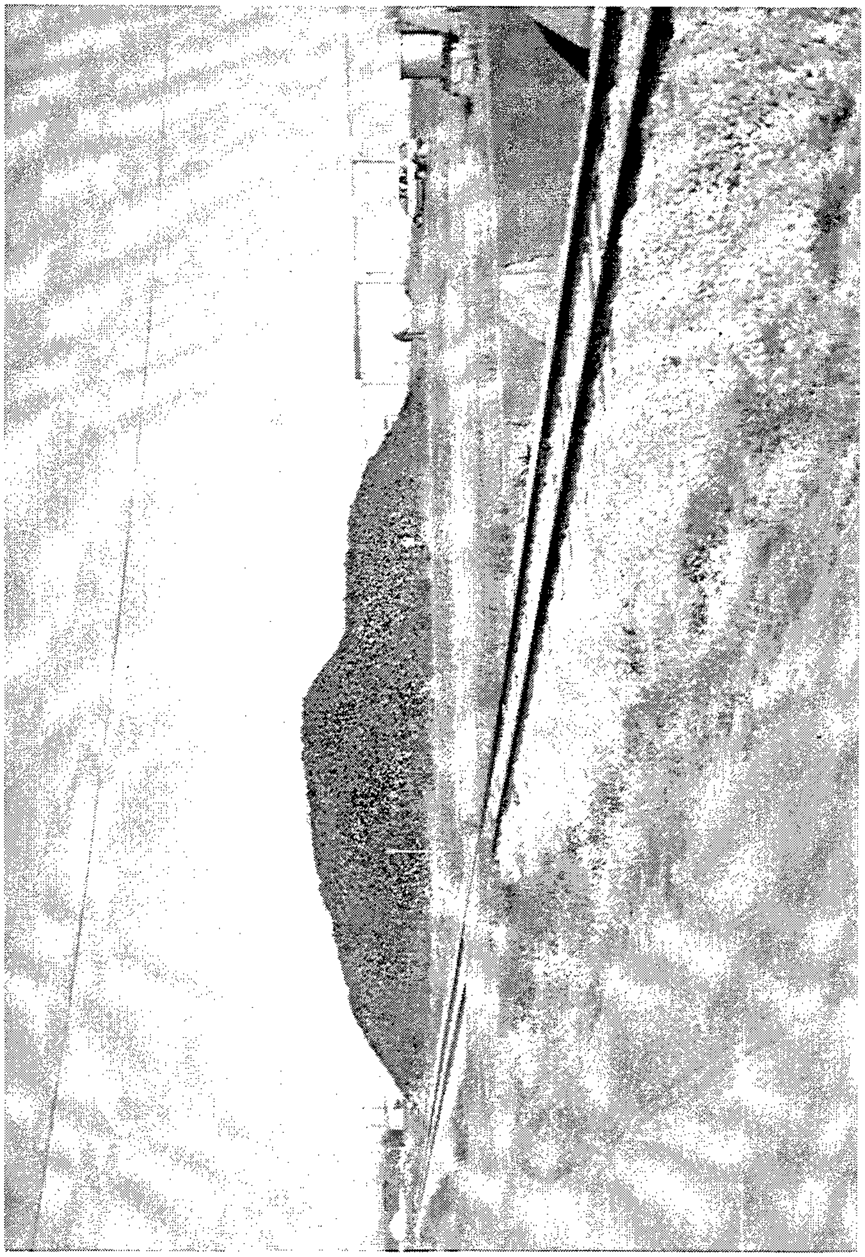


Figure A-23. Pile FM-1, Seneca Army Depot, NY

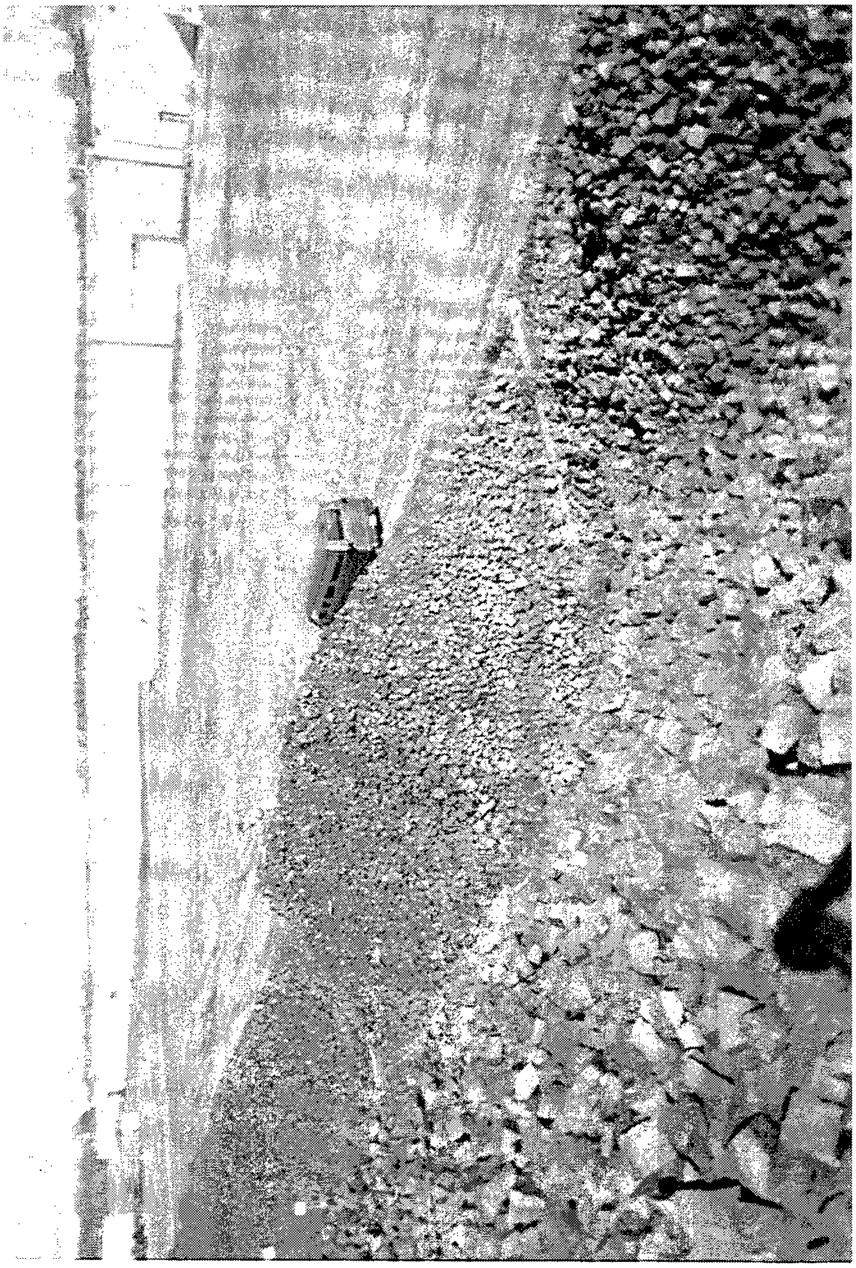


Figure A-24. Piles #22 (center) and #14 (back left) as viewed from Pile FM-1, Seneca Army Depot, NY

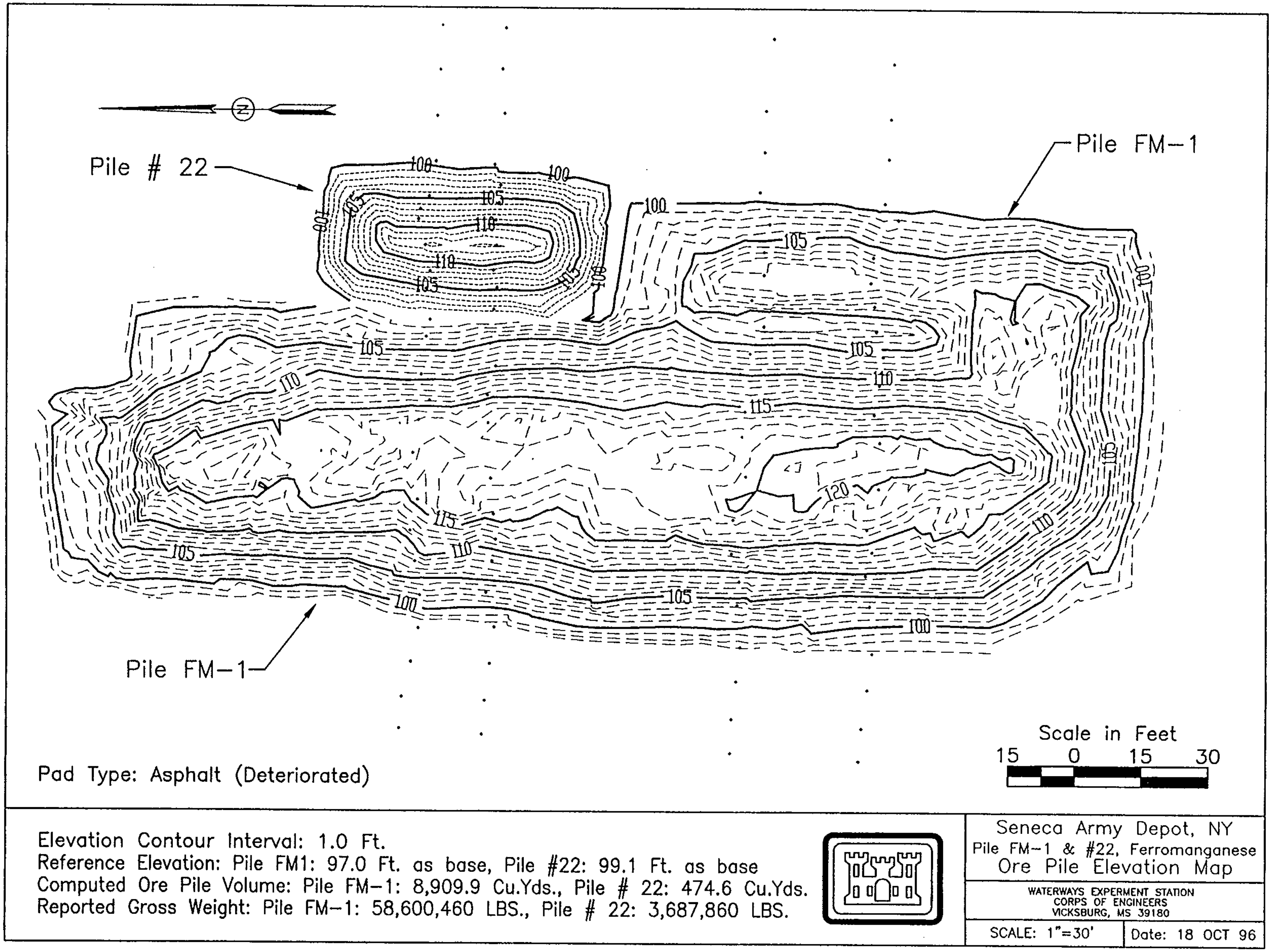


Figure A-25. Elevation contour plot of Piles FM-1 and #22, Seneca Army Depot, NY

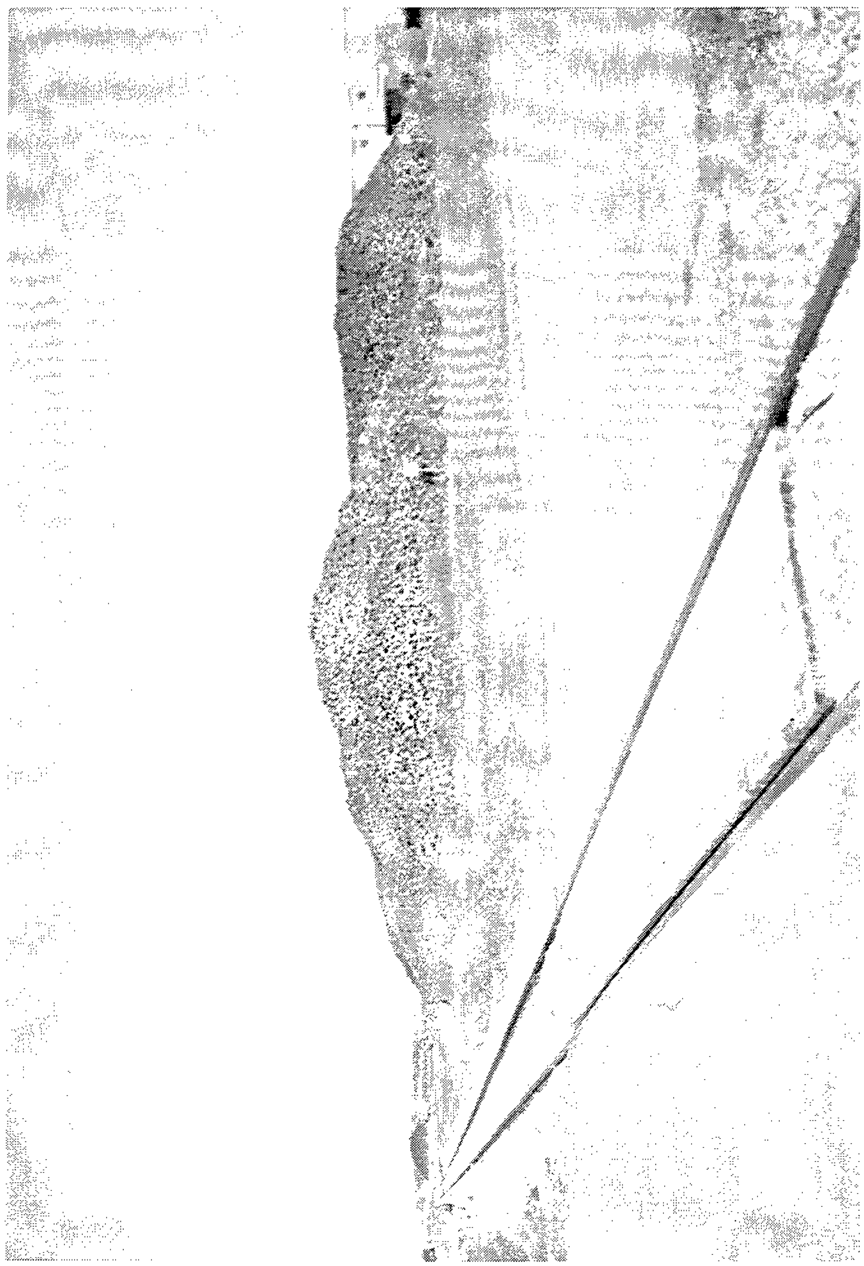


Figure A-26. Piles #23 and #10, Seneca Army Depot, NY

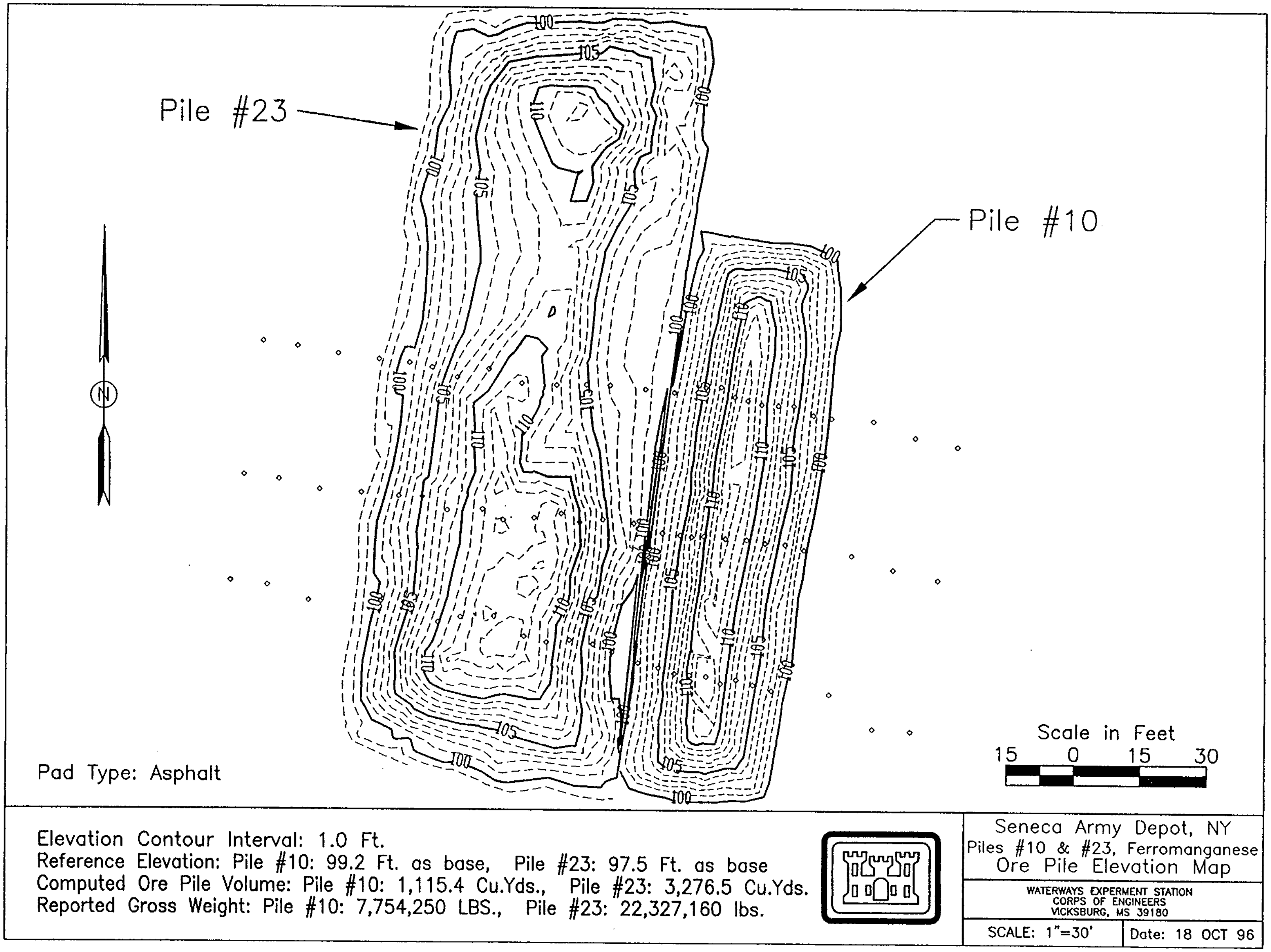


Figure A-27. Elevation contour plot of Piles #23 and #10, Seneca Army Depot, NY

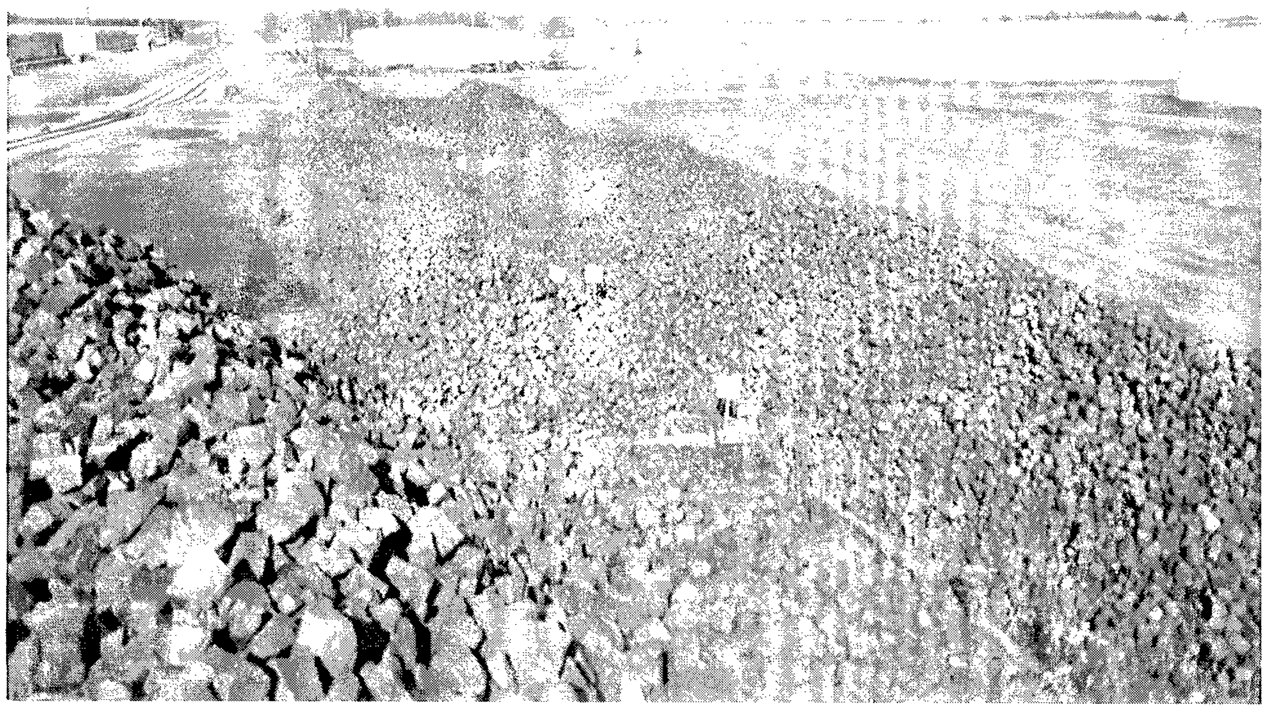
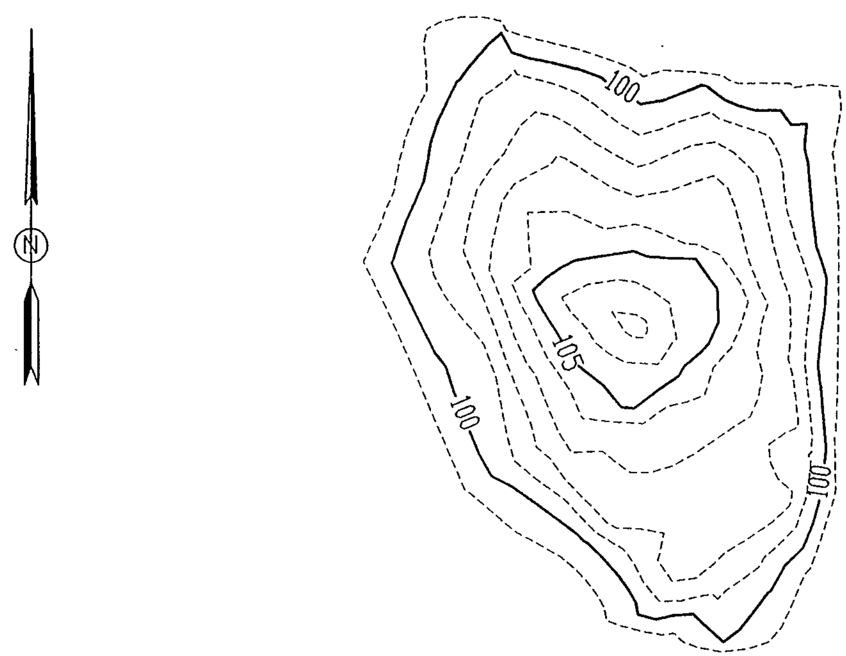
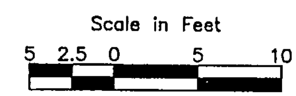


Figure A-28. Piles #34 (center), #37, #21 (back), #11 (back right), and #14 (right), Seneca Army Depot, NY





Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 98.5 Ft. as base
Computed Ore Pile Volume: 102.6 Cu.Yds.
Reported Gross Weight: 1,099,980 lbs.

Seneca Army Depot, NY
Pile #34, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=10'   Date: 21 OCT 96

Figure A-29. Elevation contour plot of Pile #34, Seneca Army Depot, NY

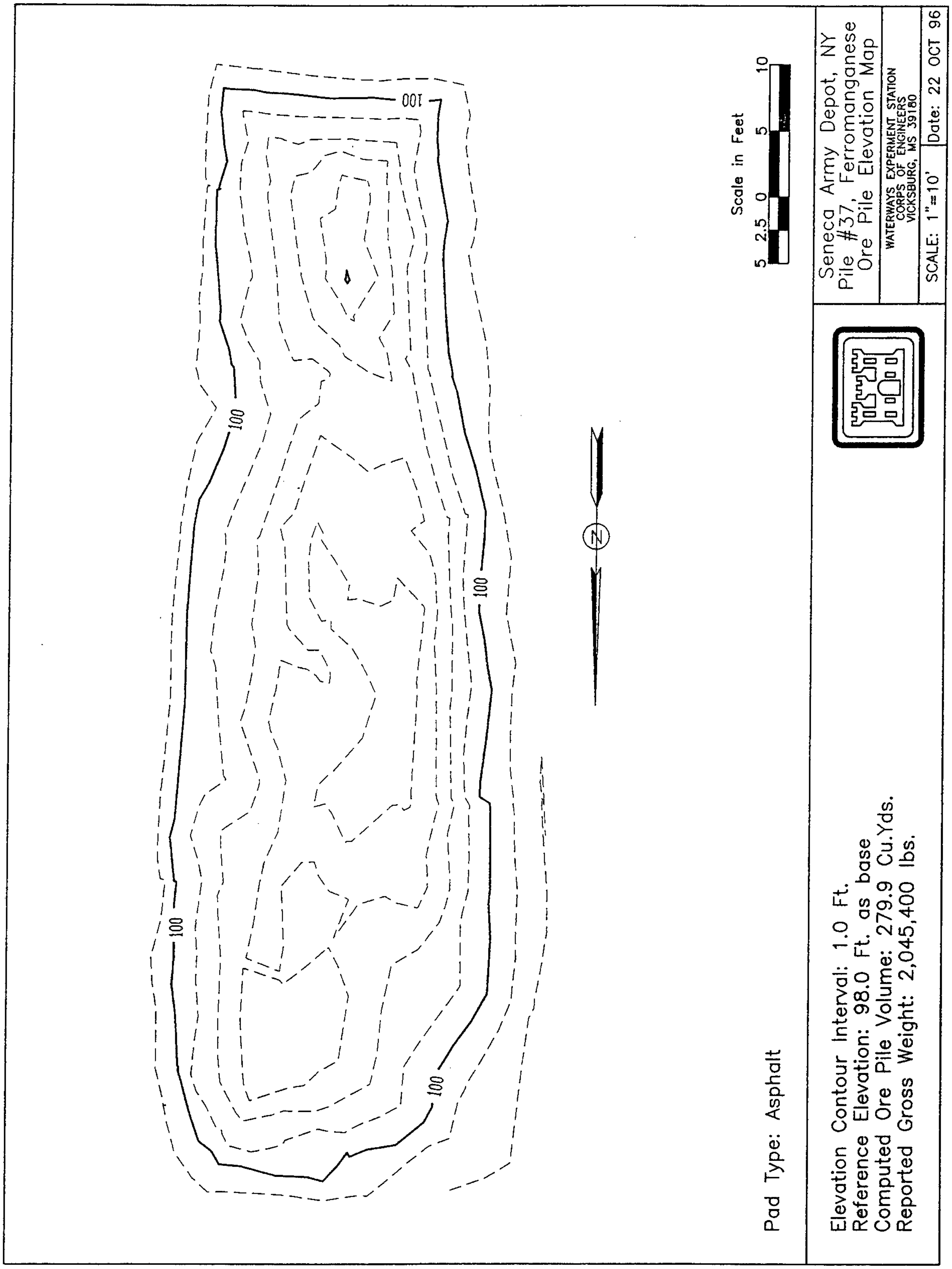


Figure A-30. Elevation contour plot of Pile #37, Seneca Army Depot, NY

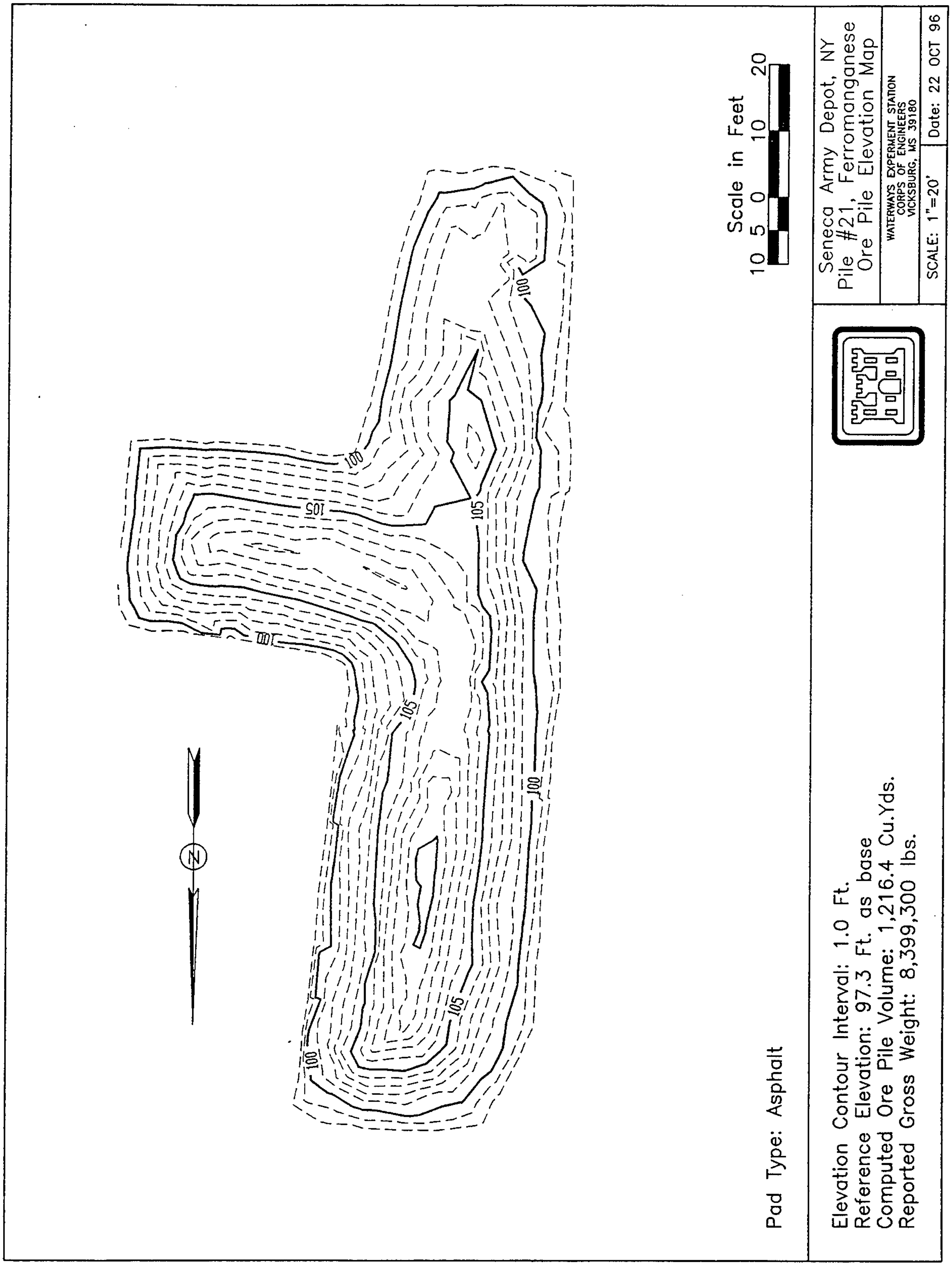


Figure A-31. Elevation contour plot of Pile #21, Seneca Army Depot, NY

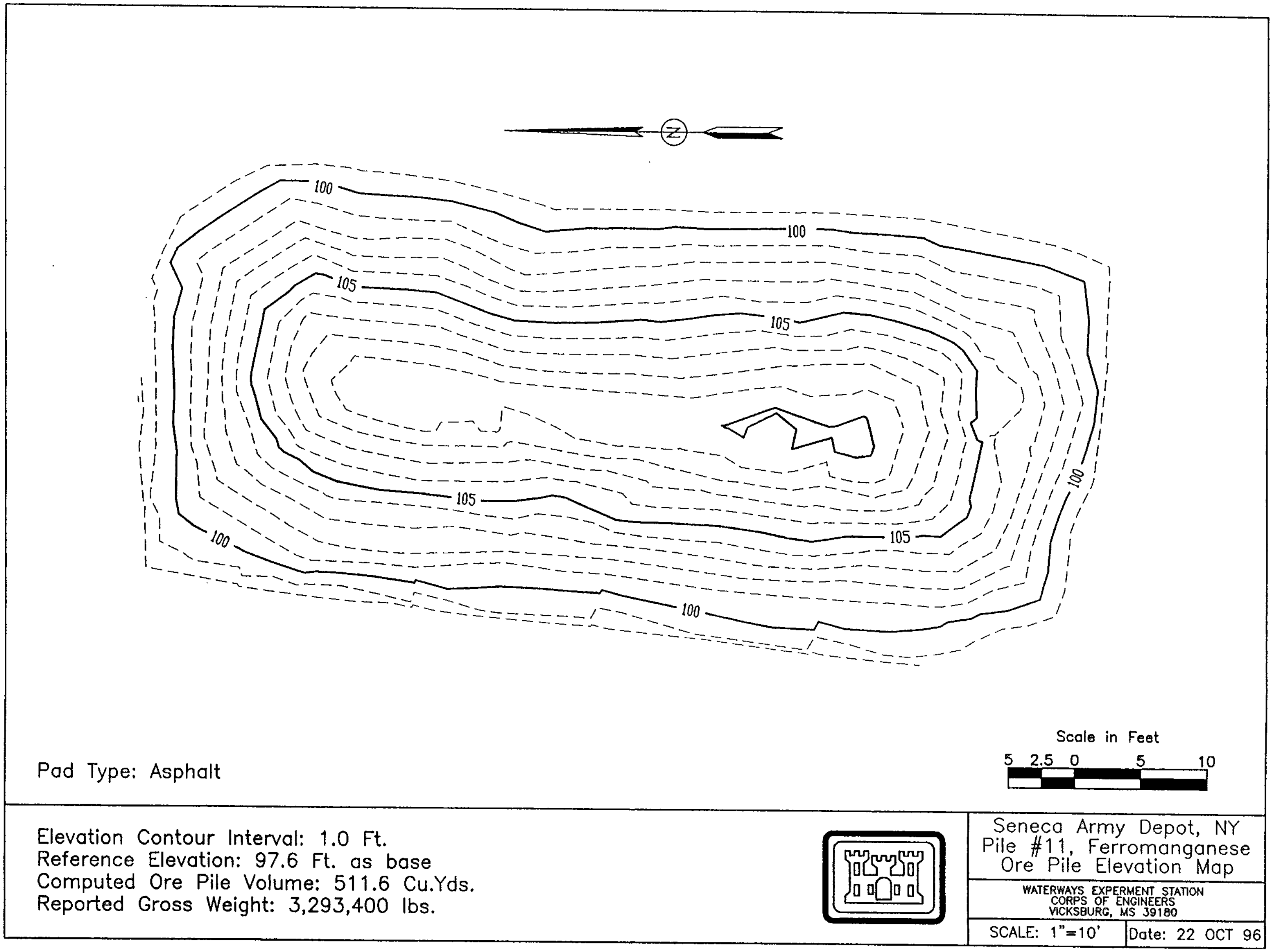


Figure A-32. Elevation contour plot of Pile #11, Seneca Army Depot, NY

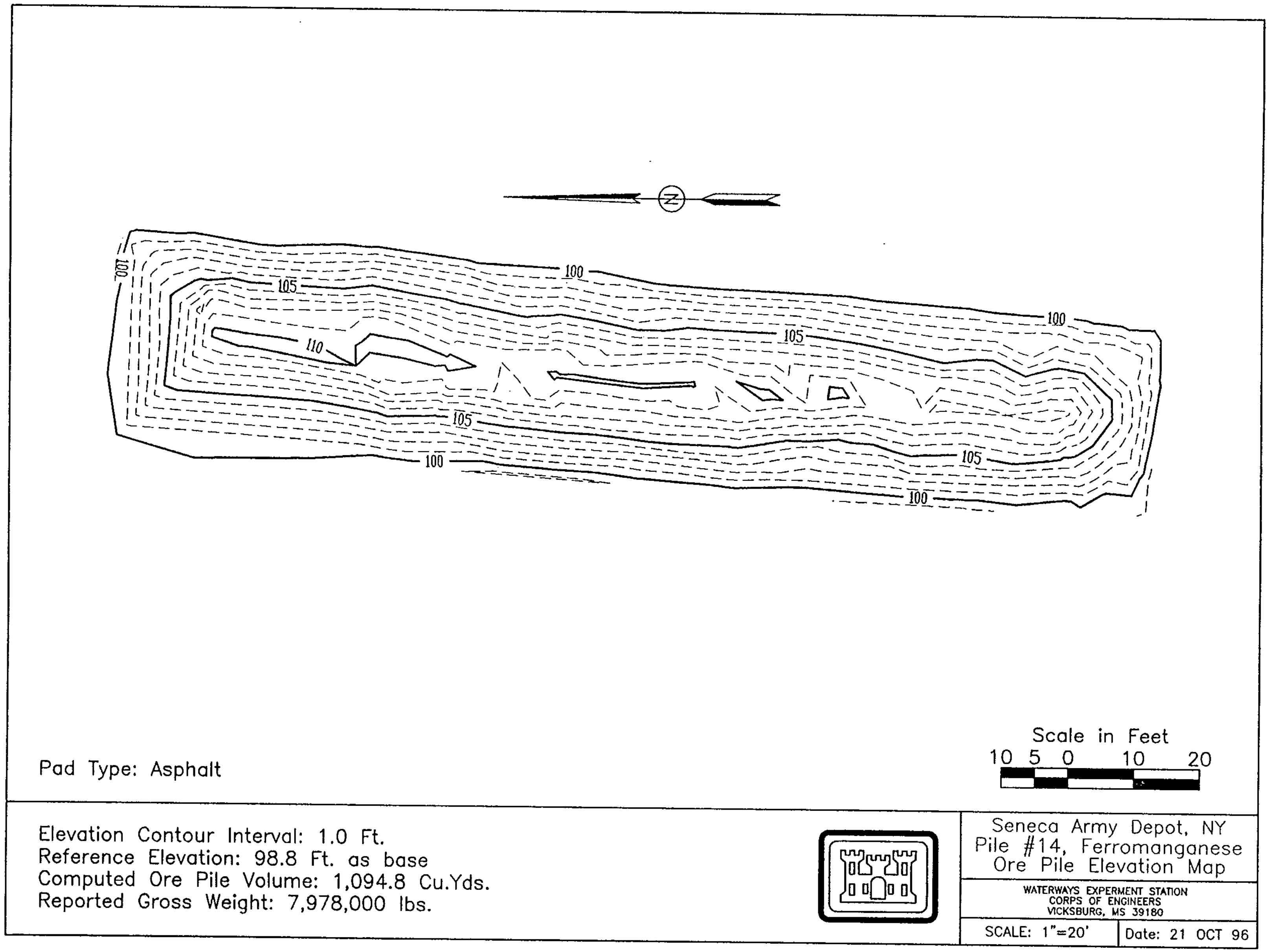


Figure A-33. Elevation contour plot of Pile #14, Seneca Army Depot, NY

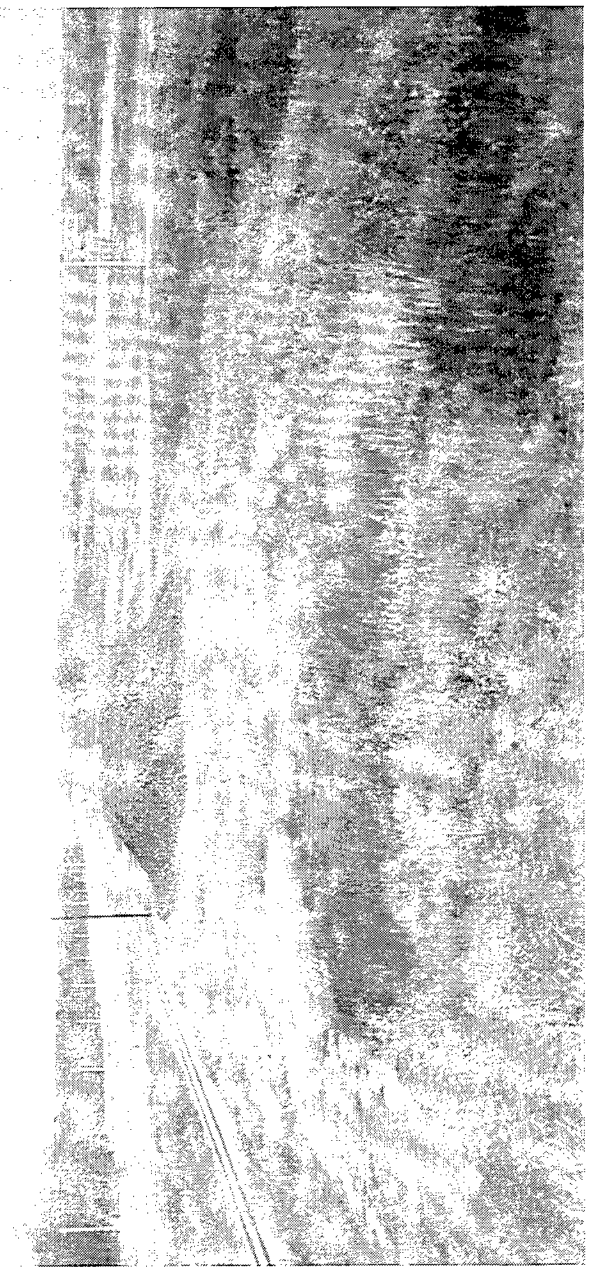


Figure A-34. Pile #31 as viewed from Pile #40, Seneca Army Depot, NY

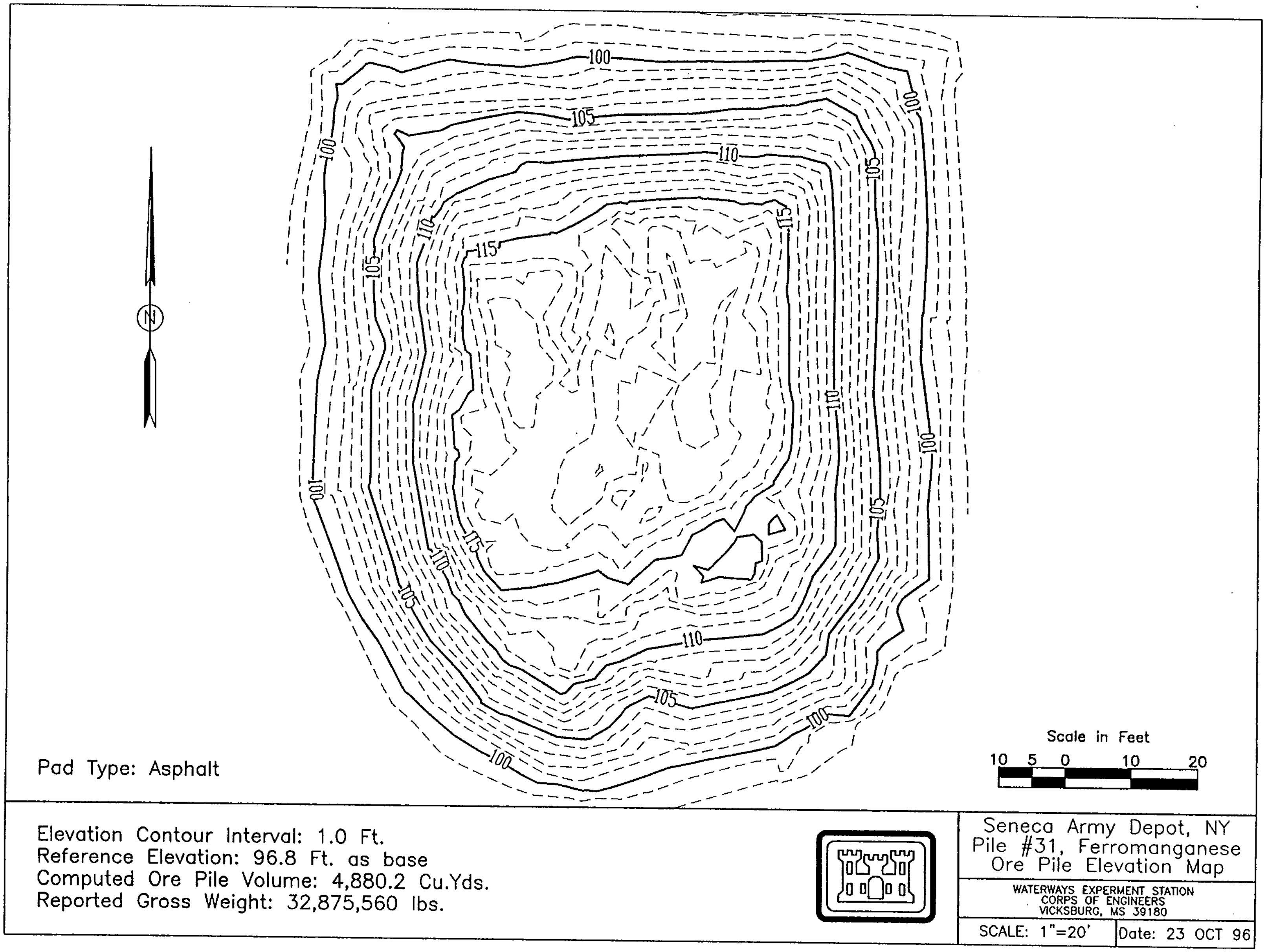


Figure A-35. Elevation contour plot of Pile #31, Seneca Army Depot, NY

Appendix B
Ore Pile Elevation Contour Plots and Photographs, Unmanned Storage Facility, Large, PA

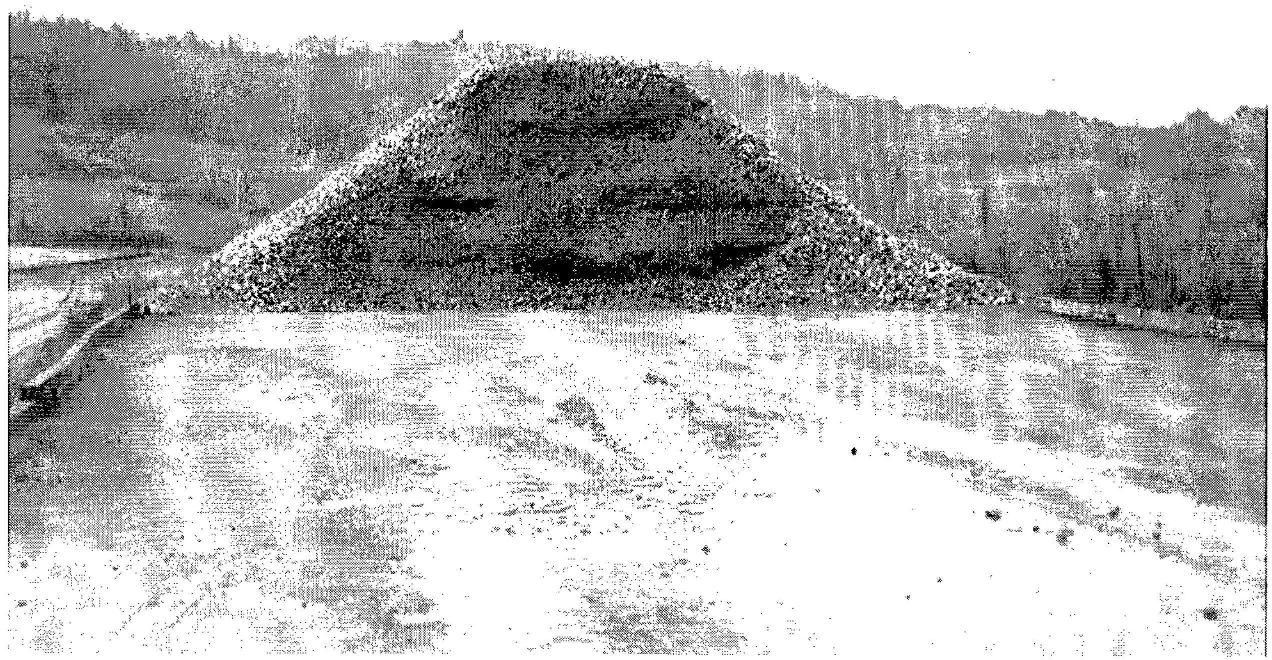


Figure B-1. North face of Pile #11 as of 19 November 1996, Large, PA. Pile #11 was being removed from the site at the time of the investigation

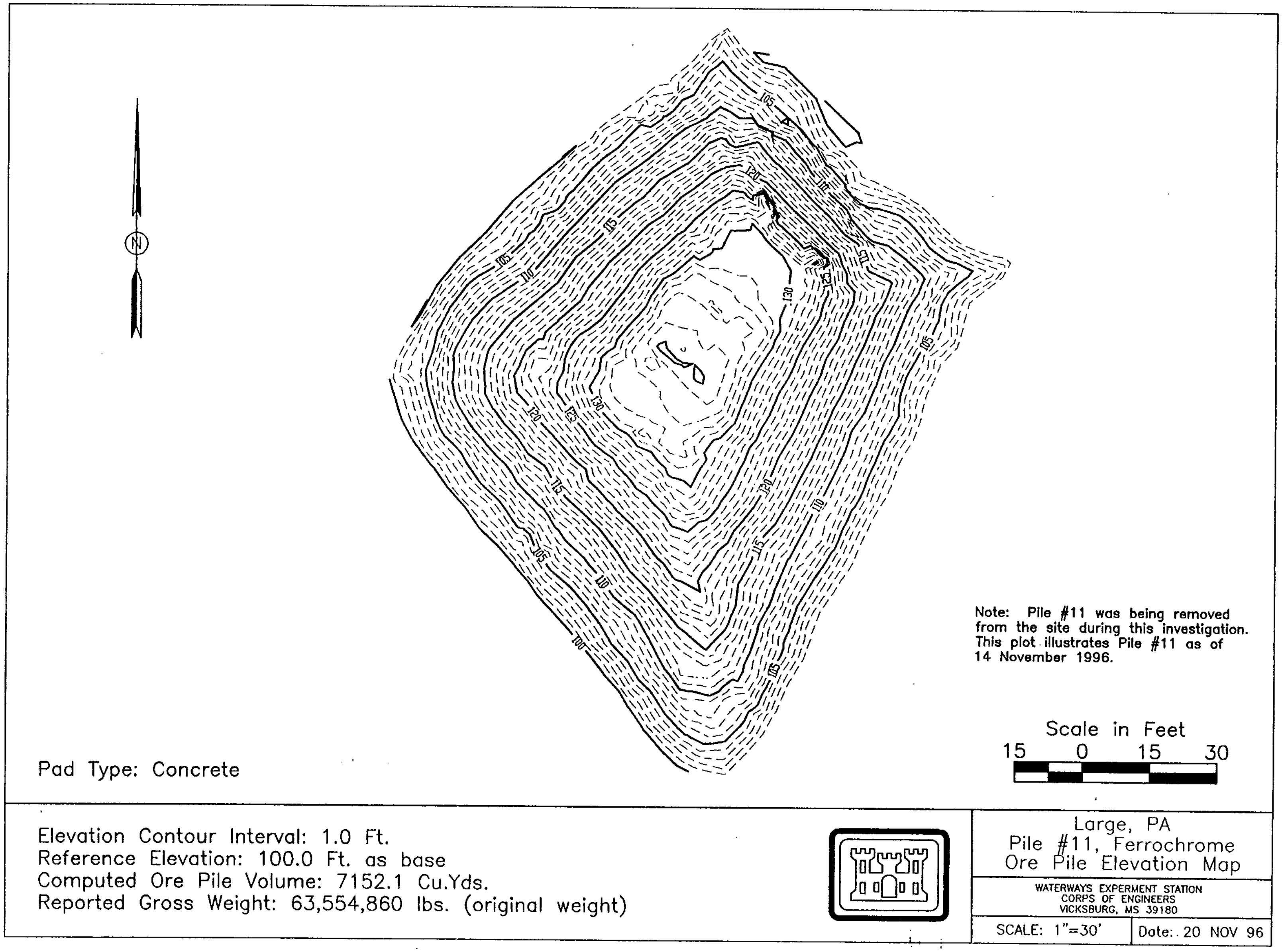


Figure B-2. Elevation contour plot of Pile #11, Large, PA

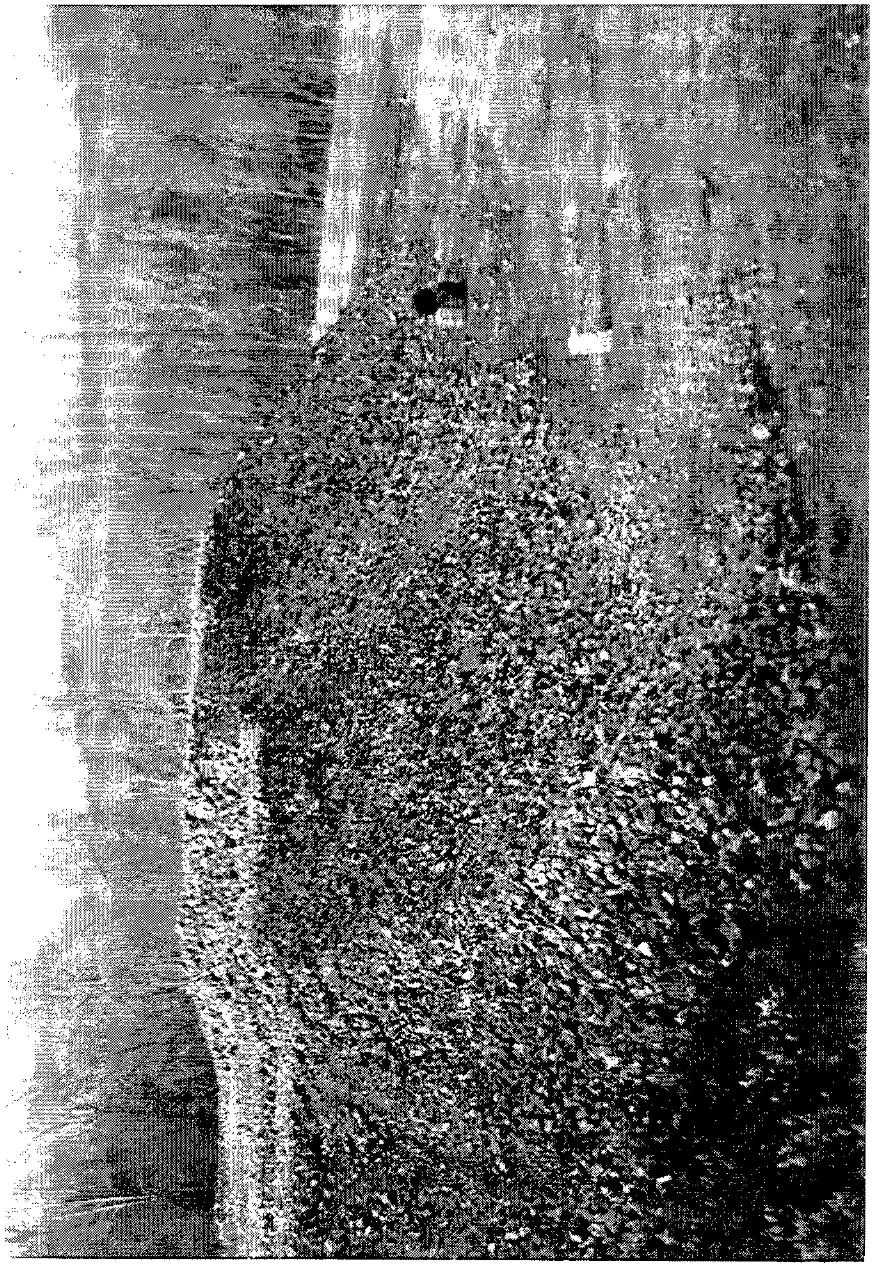


Figure B-3. Eastern side of Pile #12, Large, PA

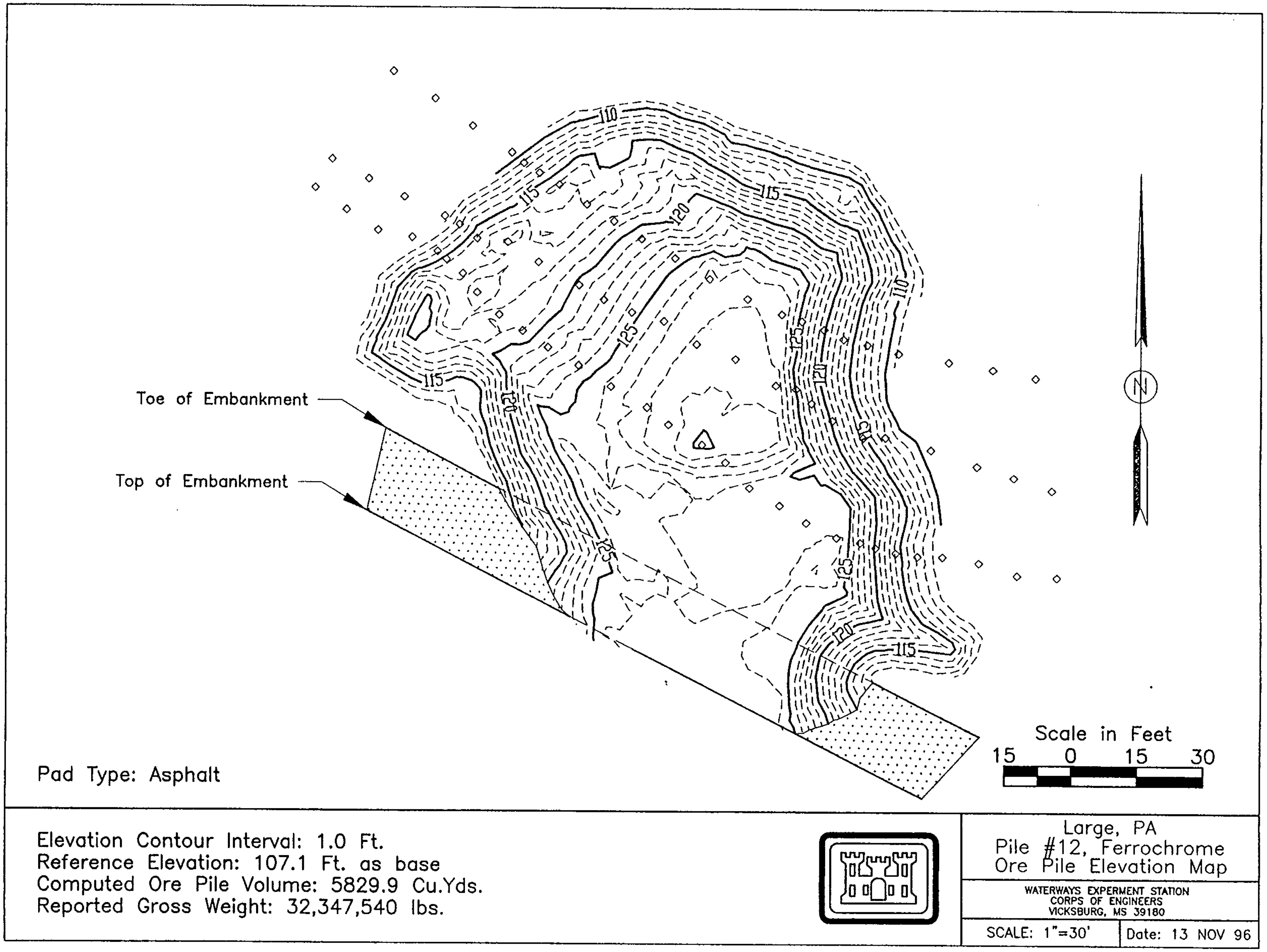


Figure B-4. Elevation contour plot of Pile #12, Large, PA

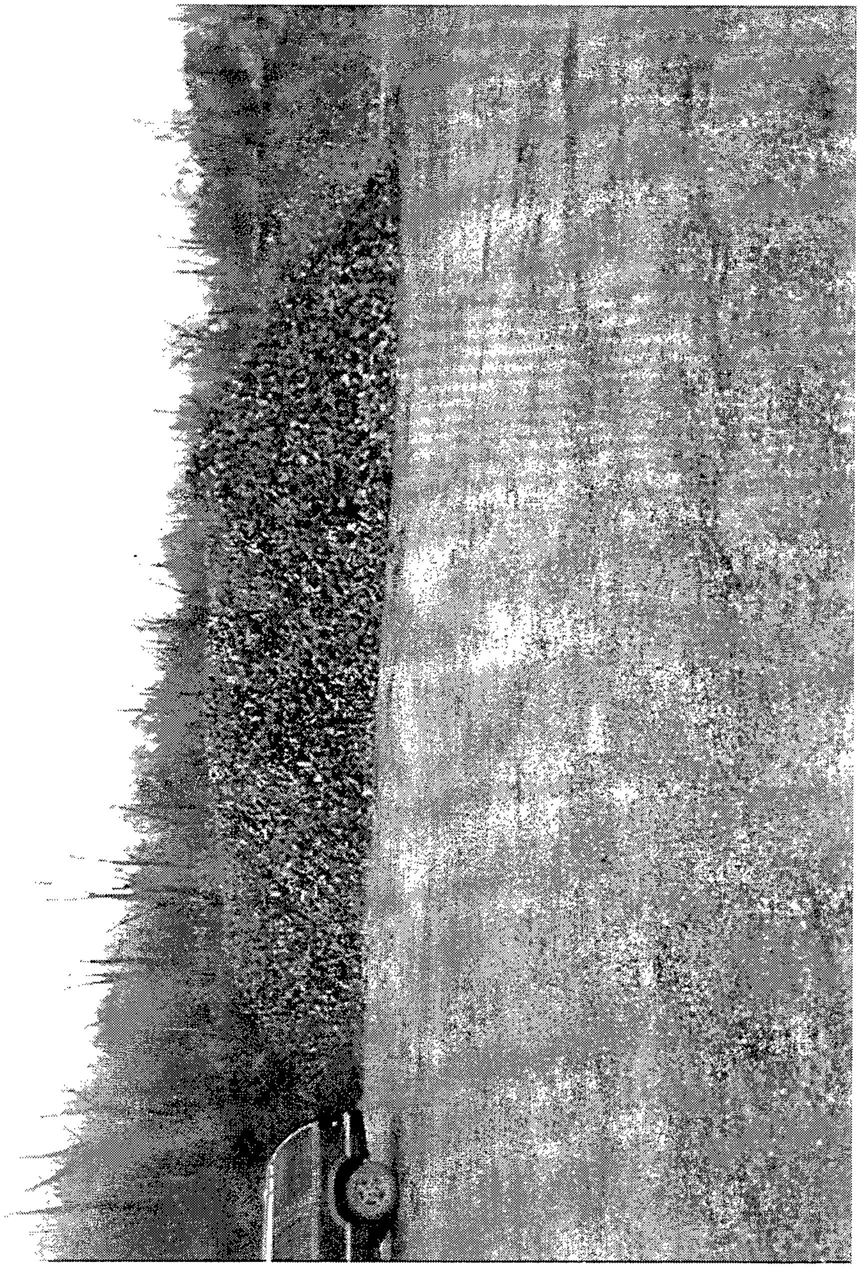


Figure B-5. Pile #20, Large, PA

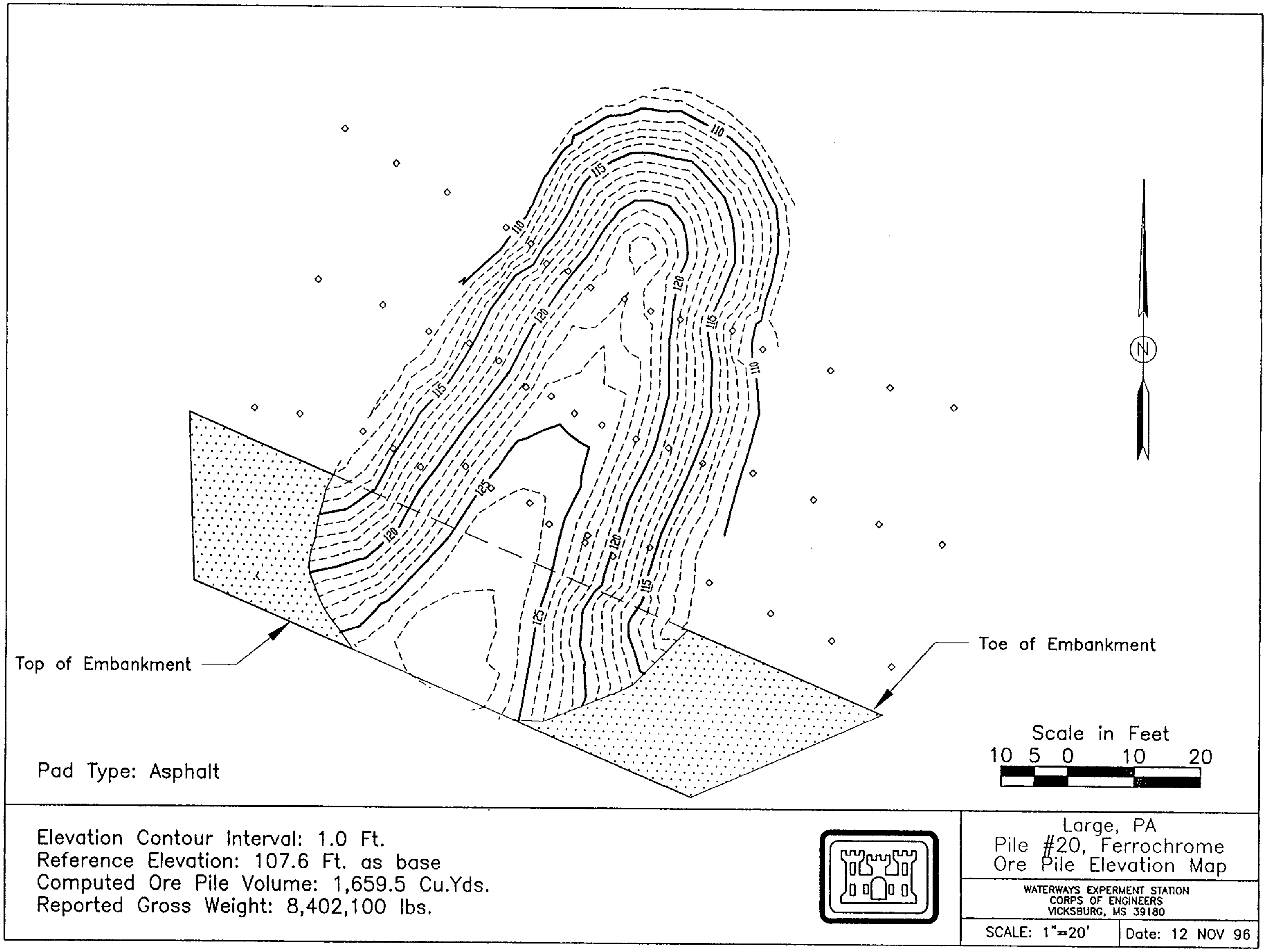


Figure B-6. Elevation contour plot of Pile #20, Large, PA

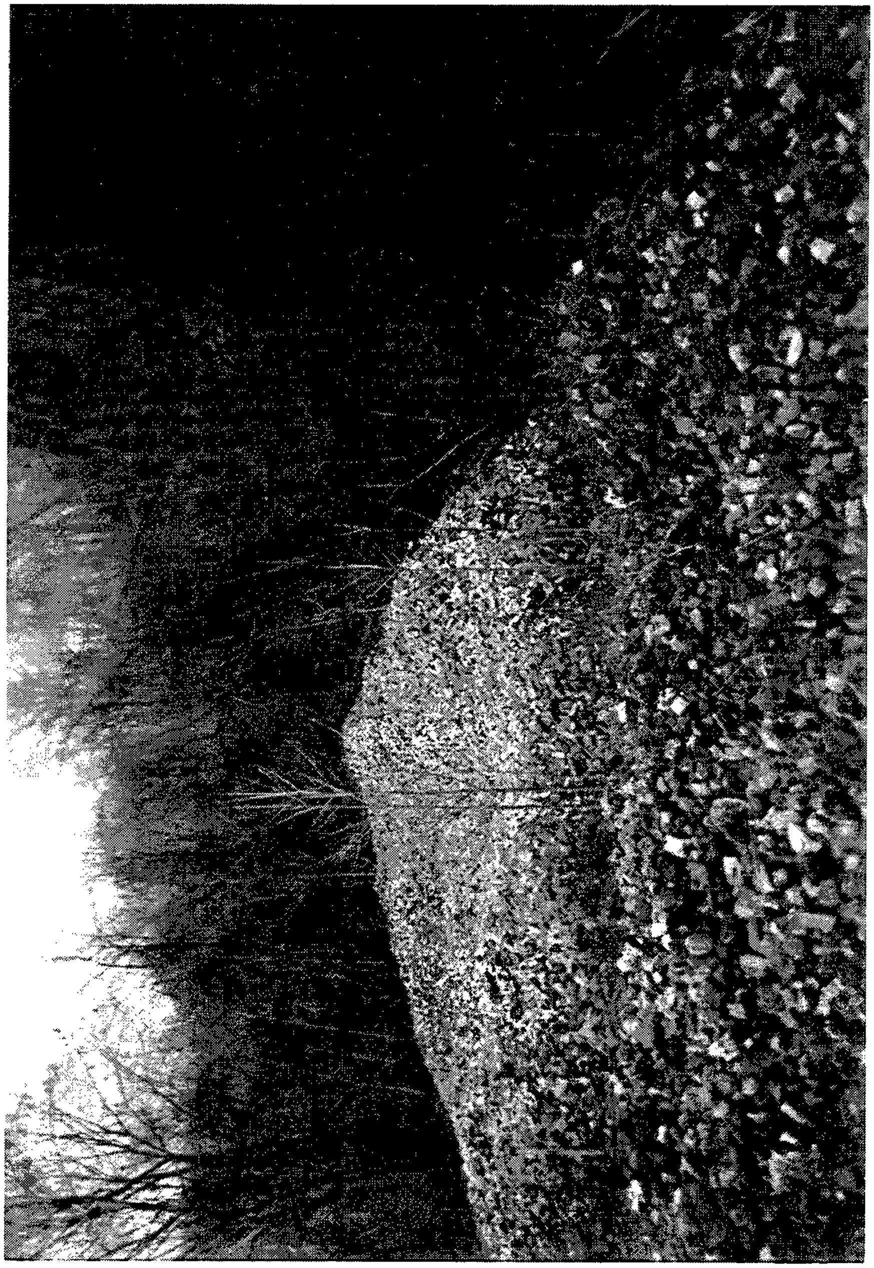
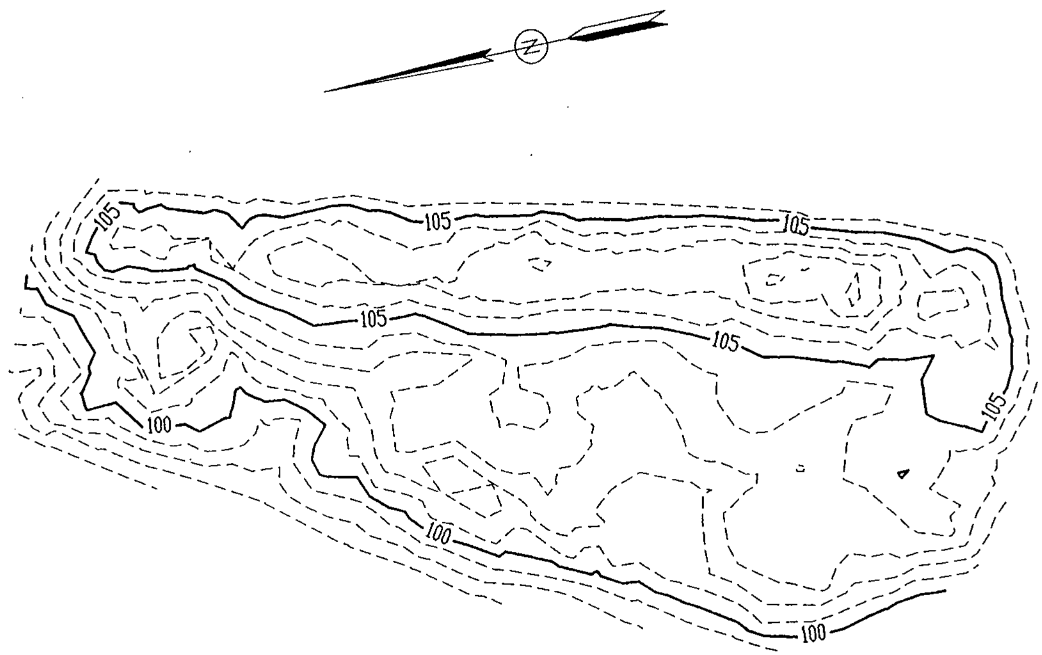


Figure B-7. Piles #24 (back) and #27, Large, PA



Pad Type: Asphalt

Scale in Feet
10 5 0 10 20

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 95.7 Ft. as base
Computed Ore Pile Volume: 702.7 Cu.Yds.
Reported Gross Weight: 3,803,230 lbs.

Large, PA
Pile #24, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' Date: 12 NOV 96

Figure B-8. Elevation contour plot of Pile #24, Large, PA

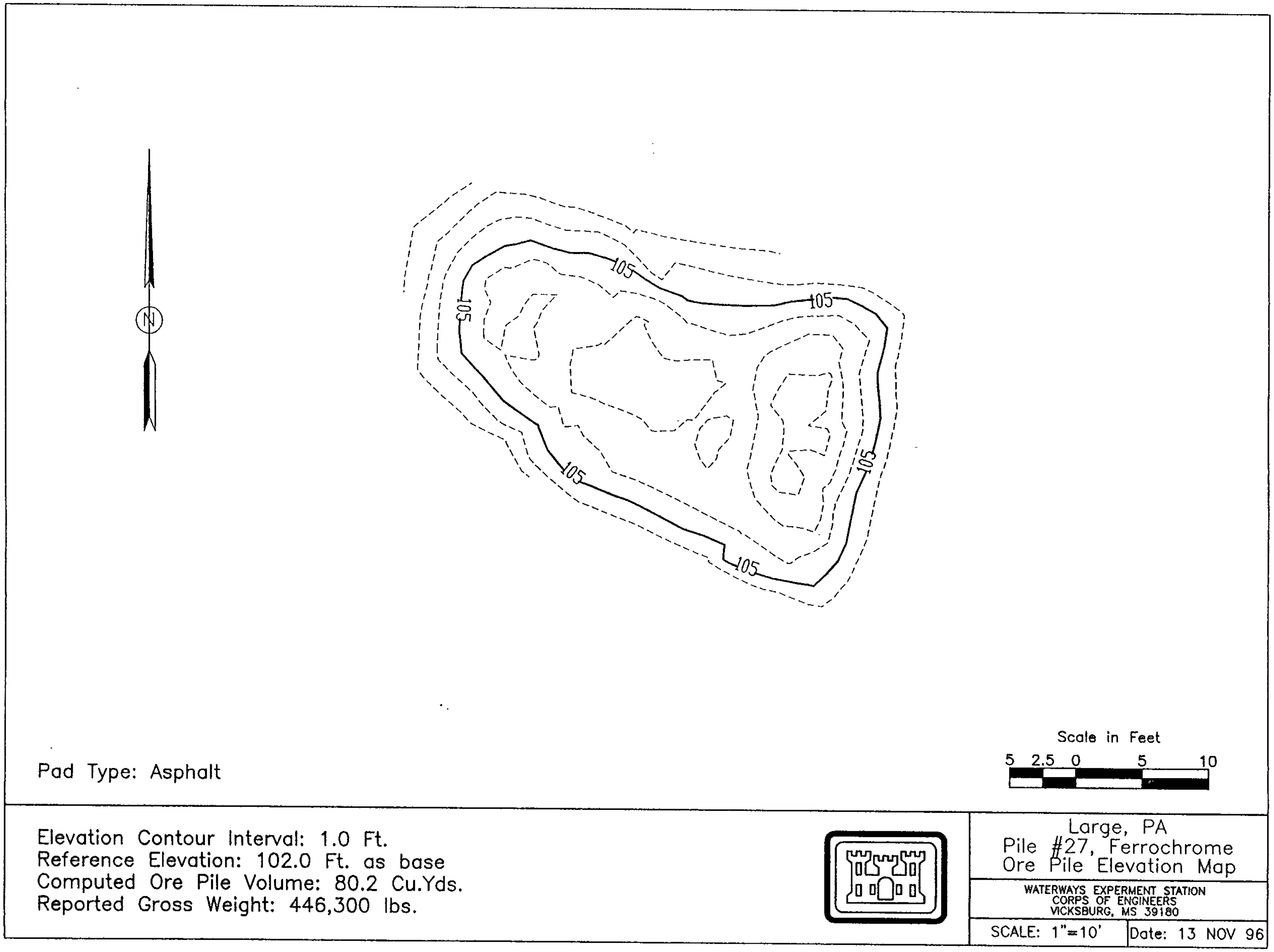


Figure B-9. Elevation contour plot of Pile #27, Large, PA

Figure B-10. Pile #25, Large, PA

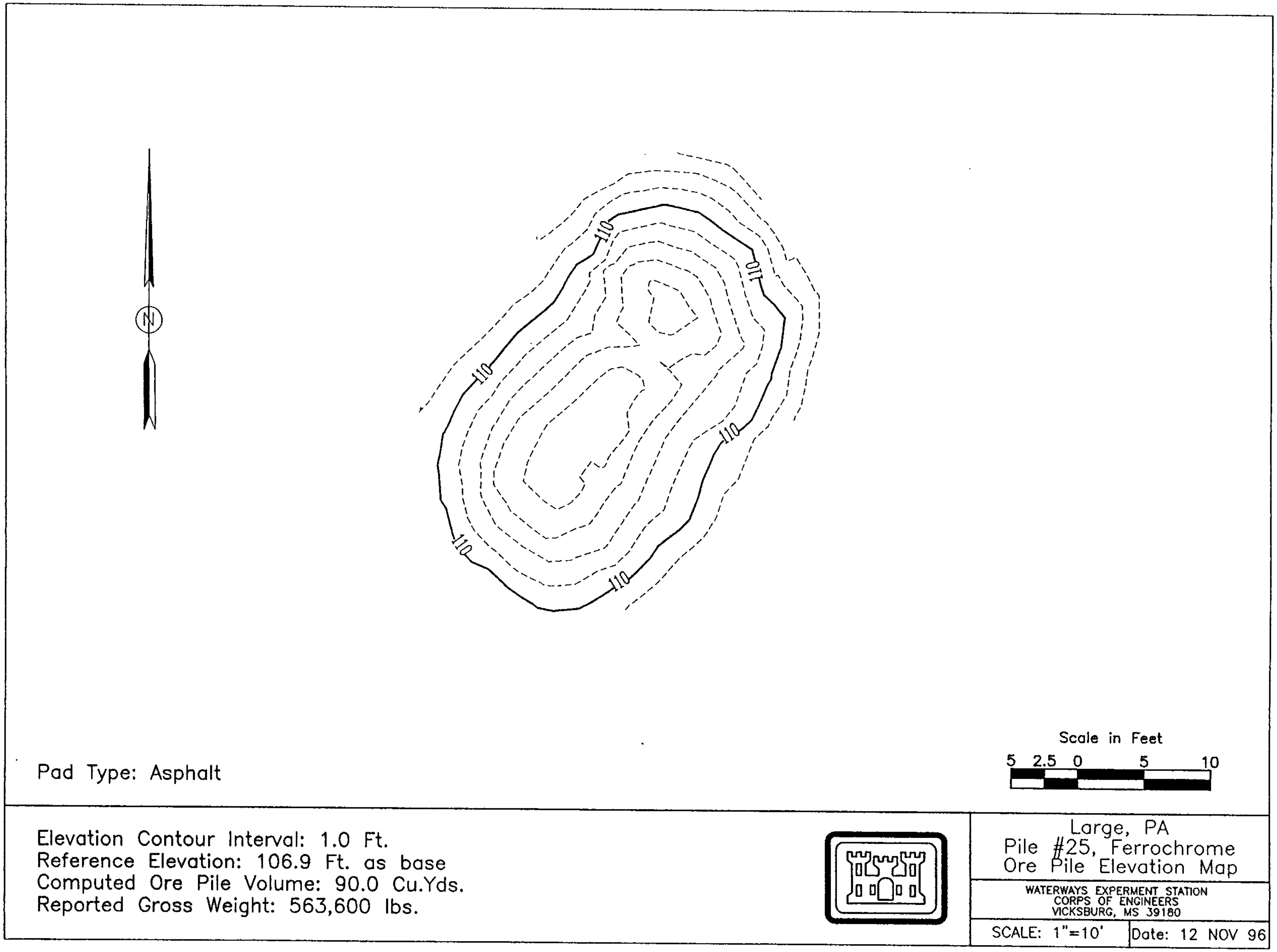


Figure B-11. Elevation contour plot of Pile #25, Large, PA

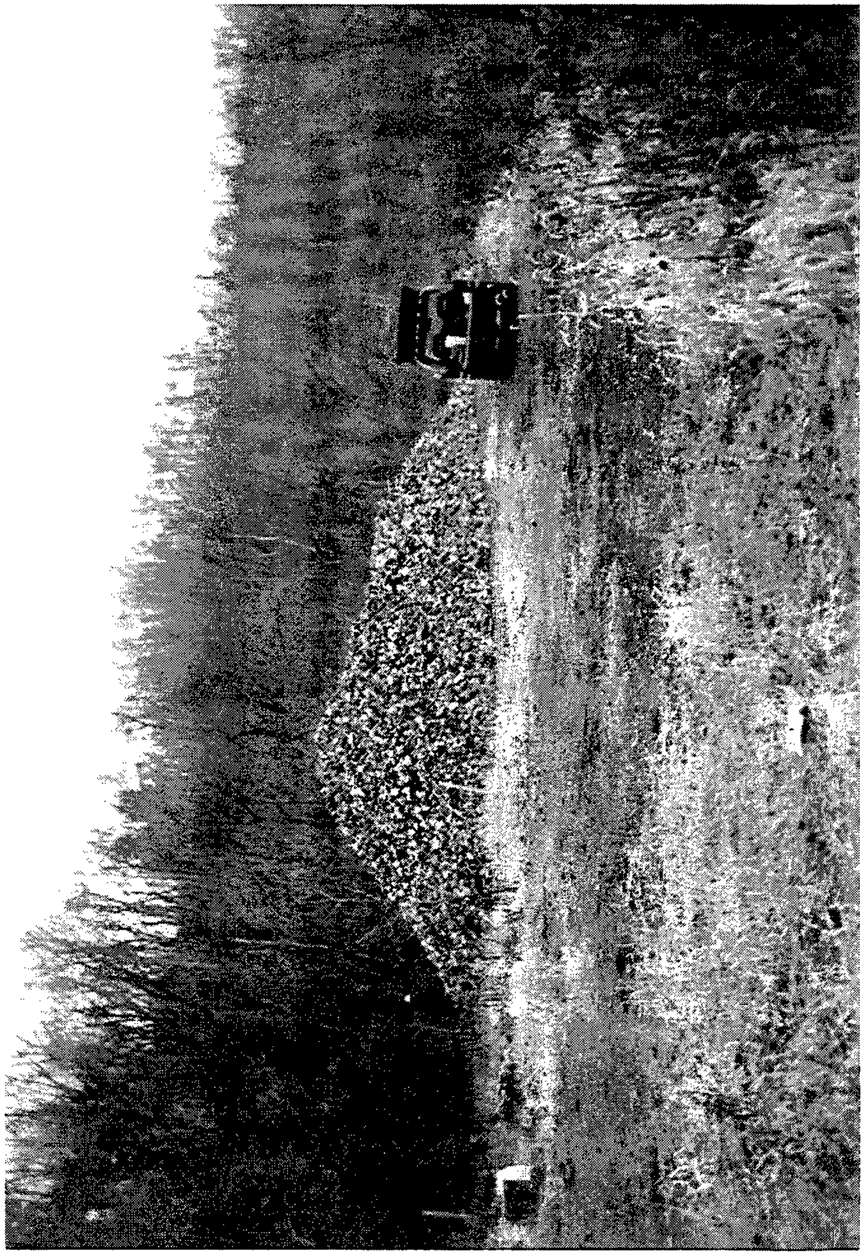
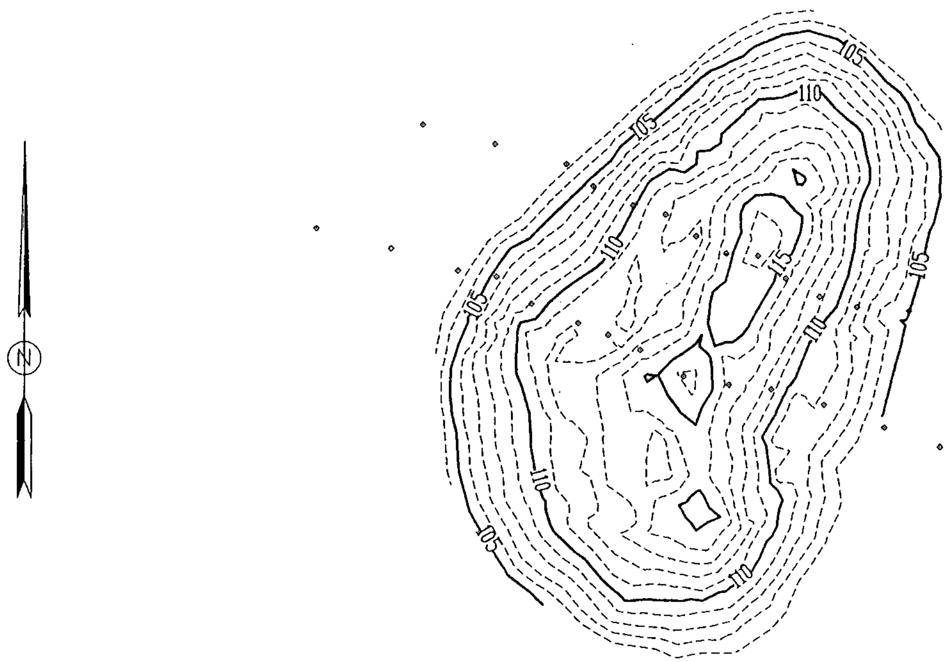


Figure B-12. Pile #26, Large, PA



Scale in Feet
10 5 0 10 20

Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 102.8 Ft. as base
Computed Ore Pile Volume: 781.0 Cu.Yds.
Reported Gross Weight: 4,911,600 lbs.

Large, PA
Pile #26, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 14 NOV 96

Figure B-13. Elevation contour plot of Pile #26, Large, PA

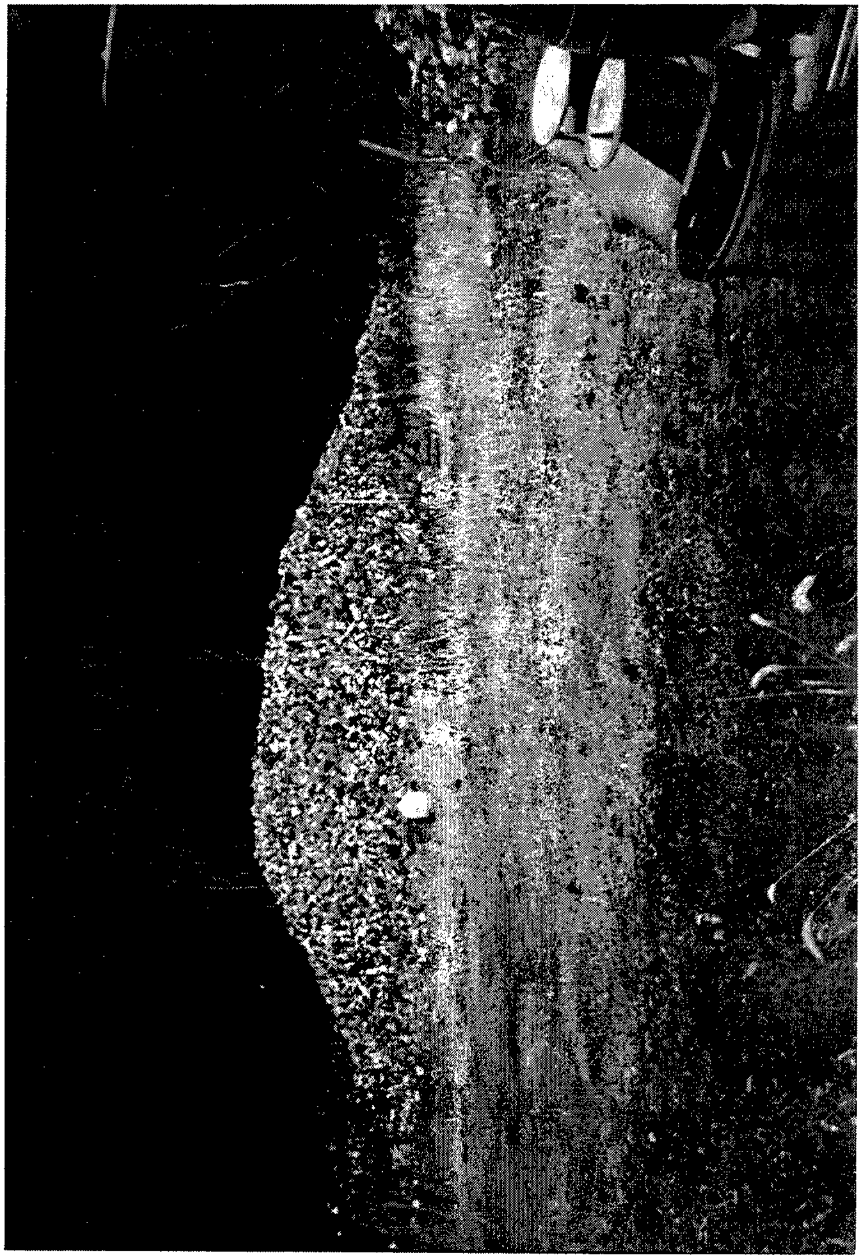


Figure B-14. Pile #28, Large, PA

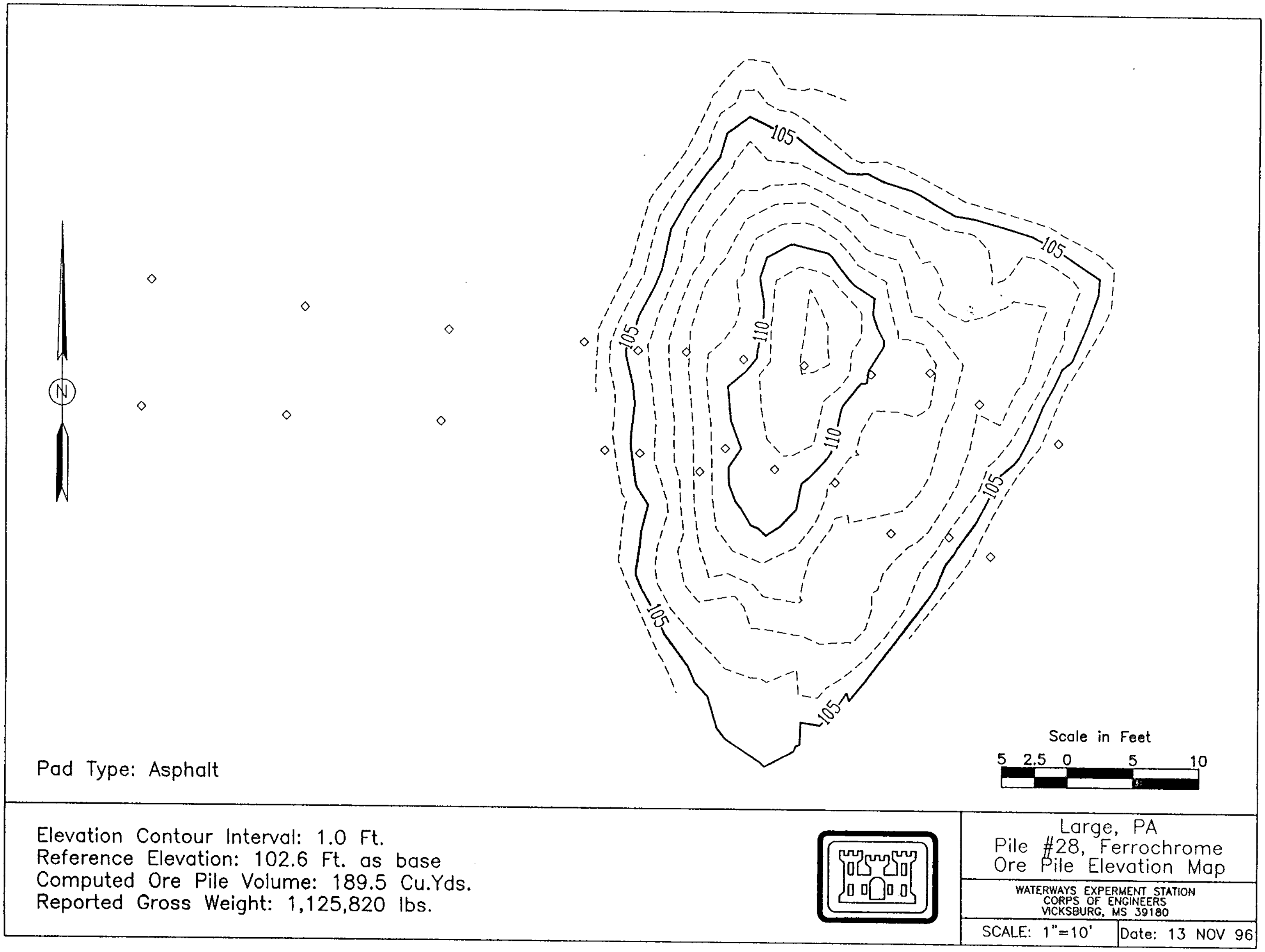


Figure B-15. Elevation contour plot of Pile #28, Large, PA

Appendix C
Ore Pile Elevation Contour Plots and Photographs, Belle Mead Depot, NJ

High-Carbon Ferrochrome

Figure C-1. Pile #15, Belle Mead Depot, NJ

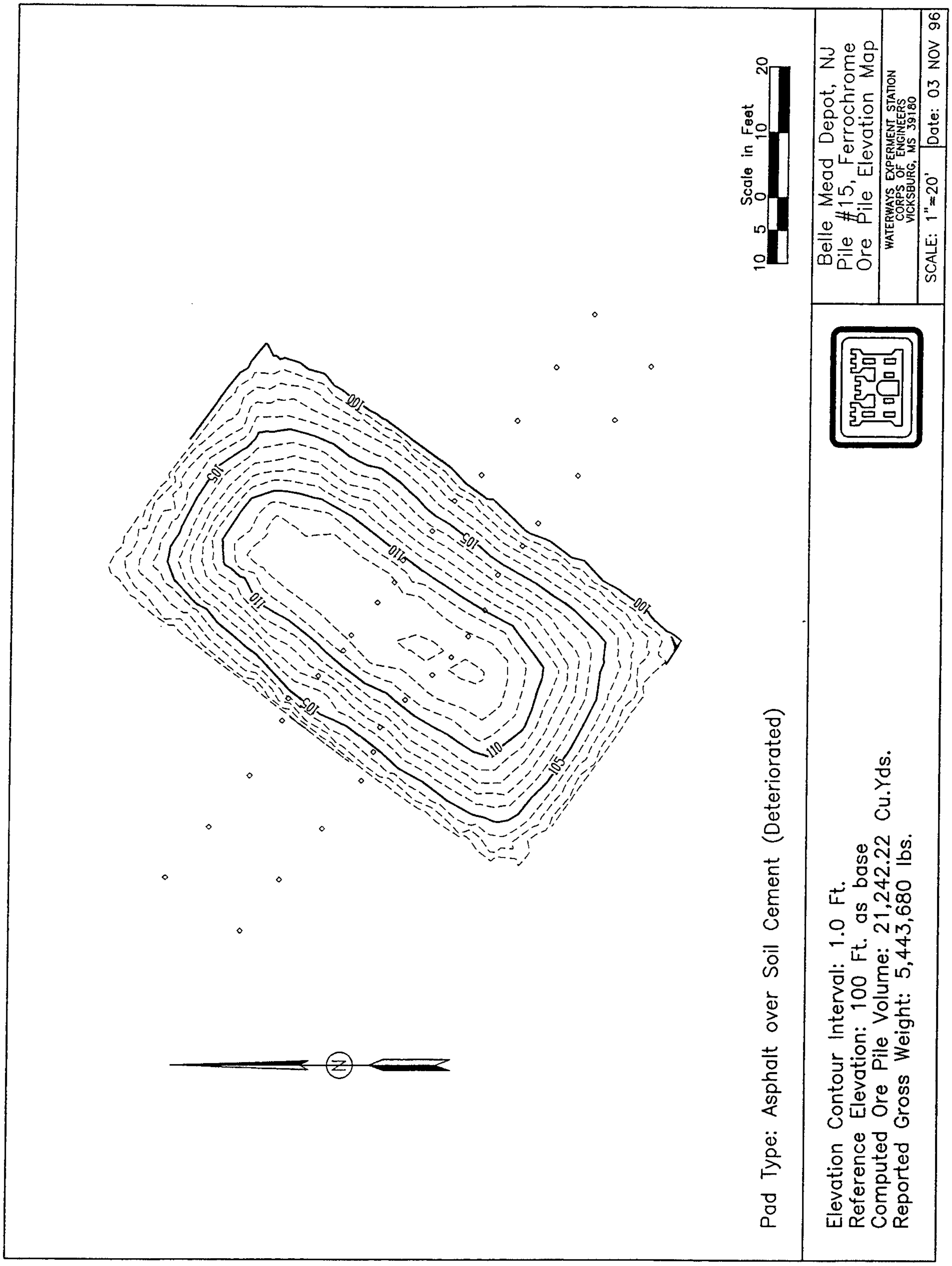


Figure C-2. Elevation contour plot of Pile #15, Belle Mead Depot, NJ

Low-Carbon Ferrochrome

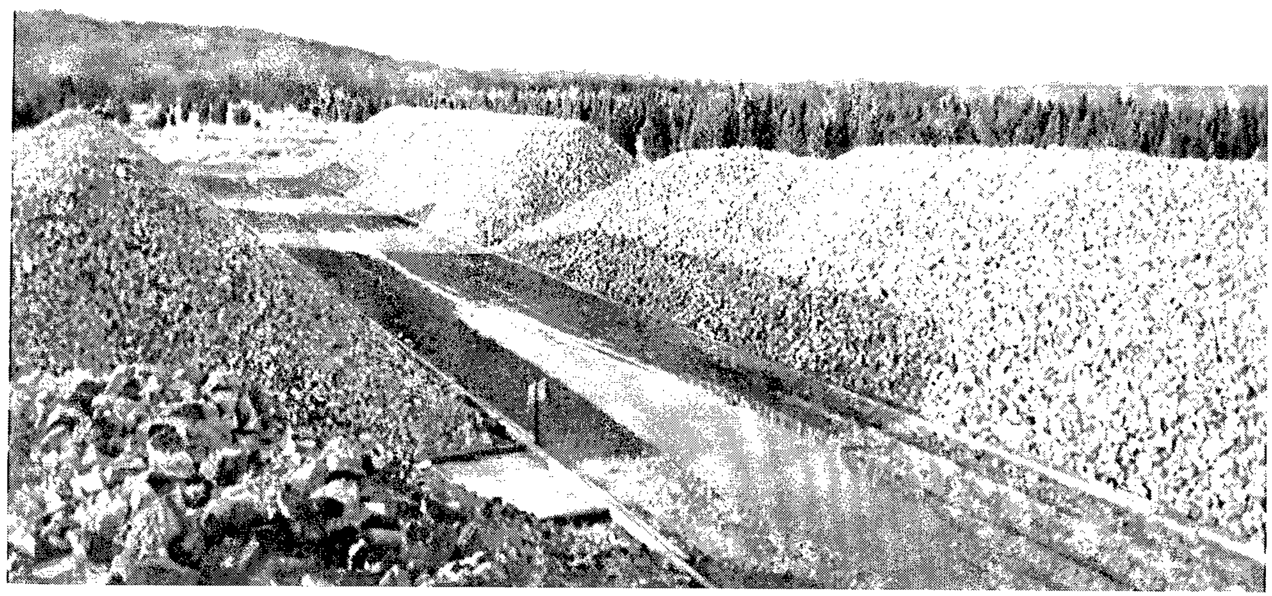
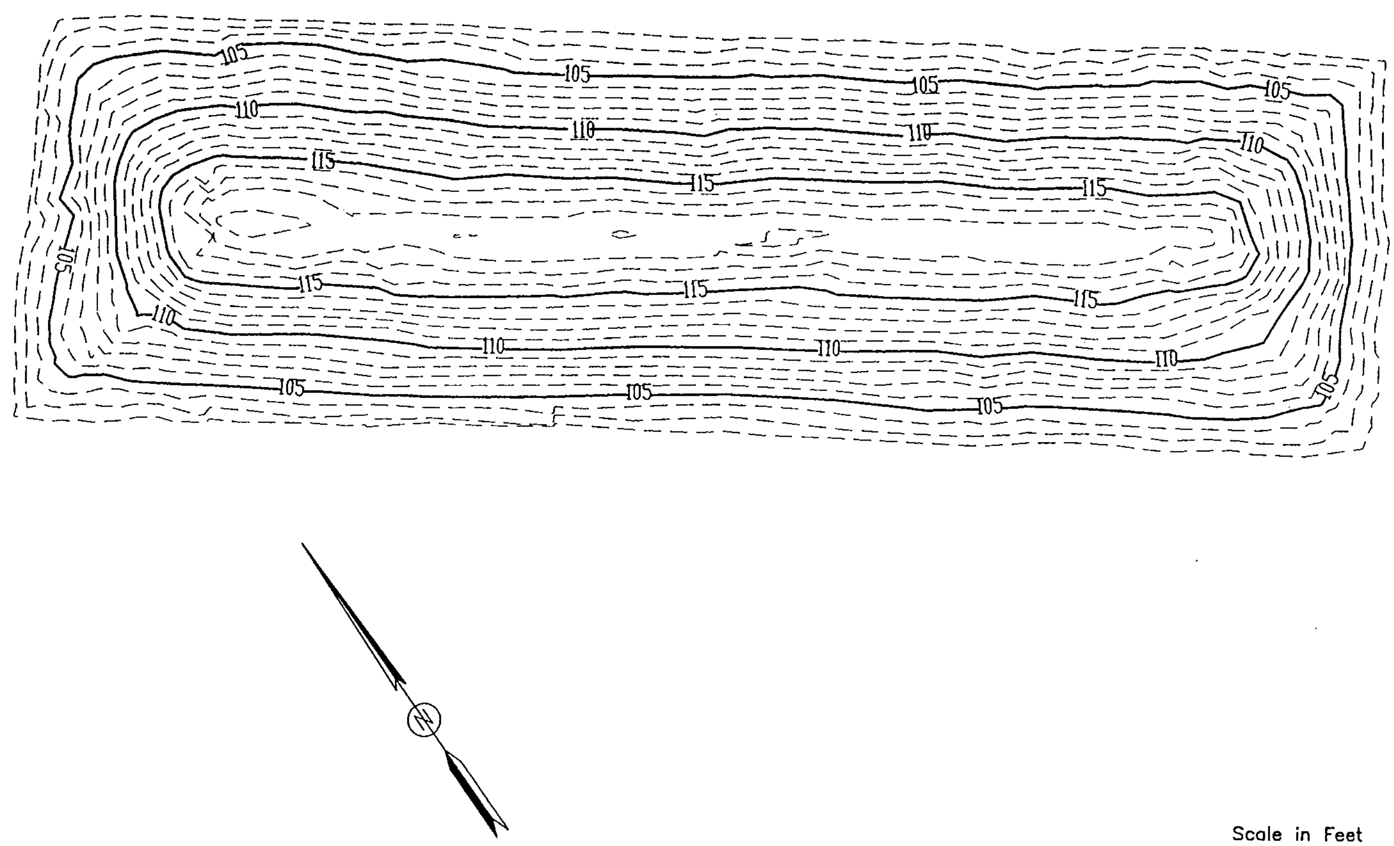


Figure C-3. Piles #2 (left) and #3 (1 of 2), Belle Mead Depot, NJ



Scale in Feet

10 5 0 10 20

Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 101.3 Ft. as base
Computed Ore Pile Volume: 2,467.5 Cu.Yds.
Reported Gross Weight: 14,482,025 lbs.

Belle Mead Depot, NJ
Pile #2, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 01 NOV 96

Figure C-4. Elevation contour plot of Pile #2, Belle Mead Depot, NJ

Figure C-5. Pile #3 (1 of 2), Belle Mead Depot, NJ

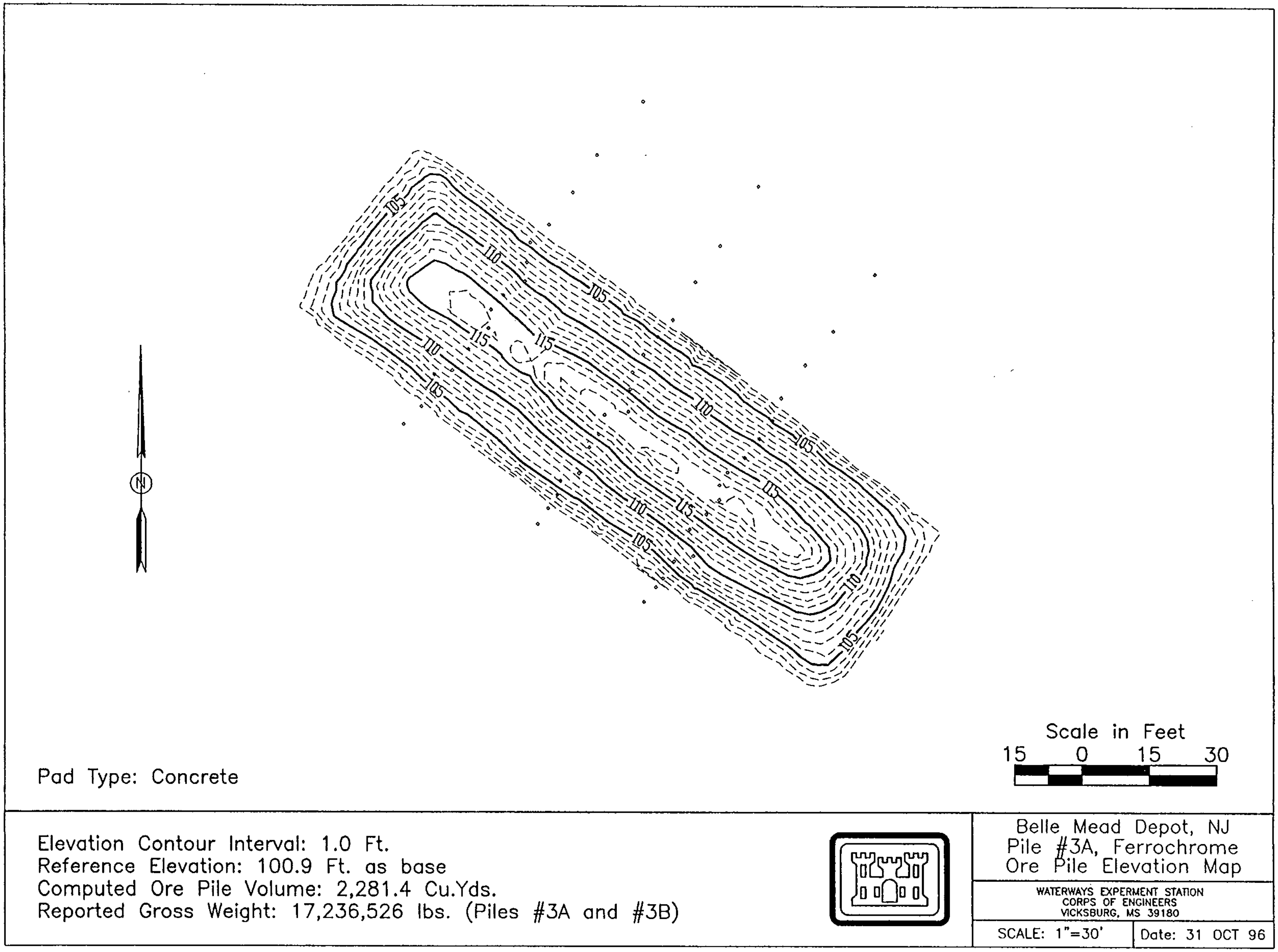


Figure C-6. Elevation contour plot of Pile #3 (1 of 2), Belle Mead Depot, NJ

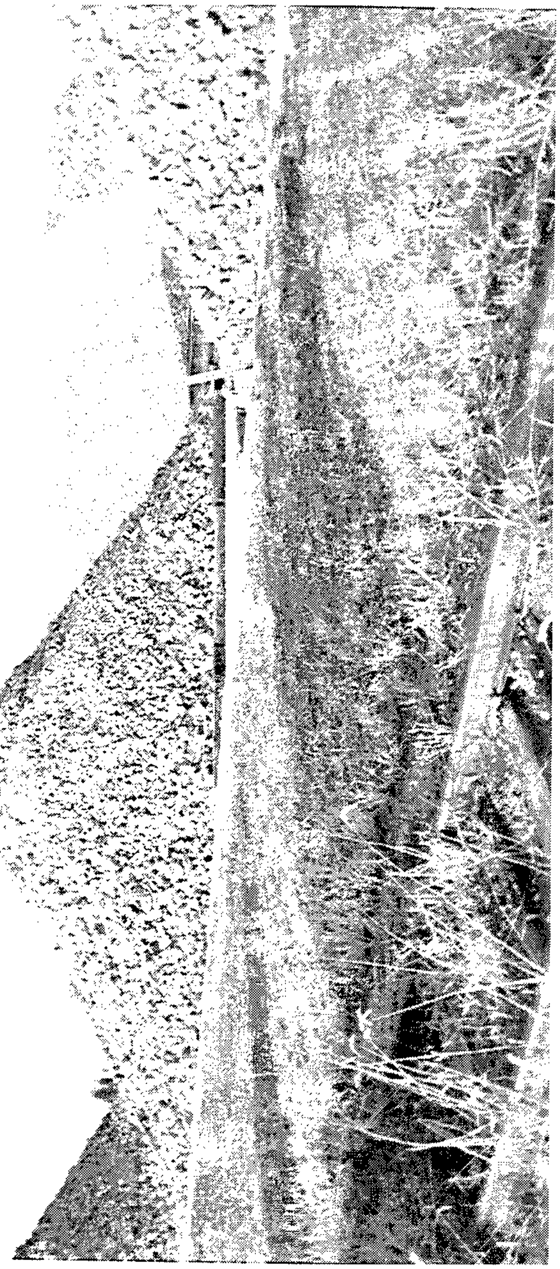
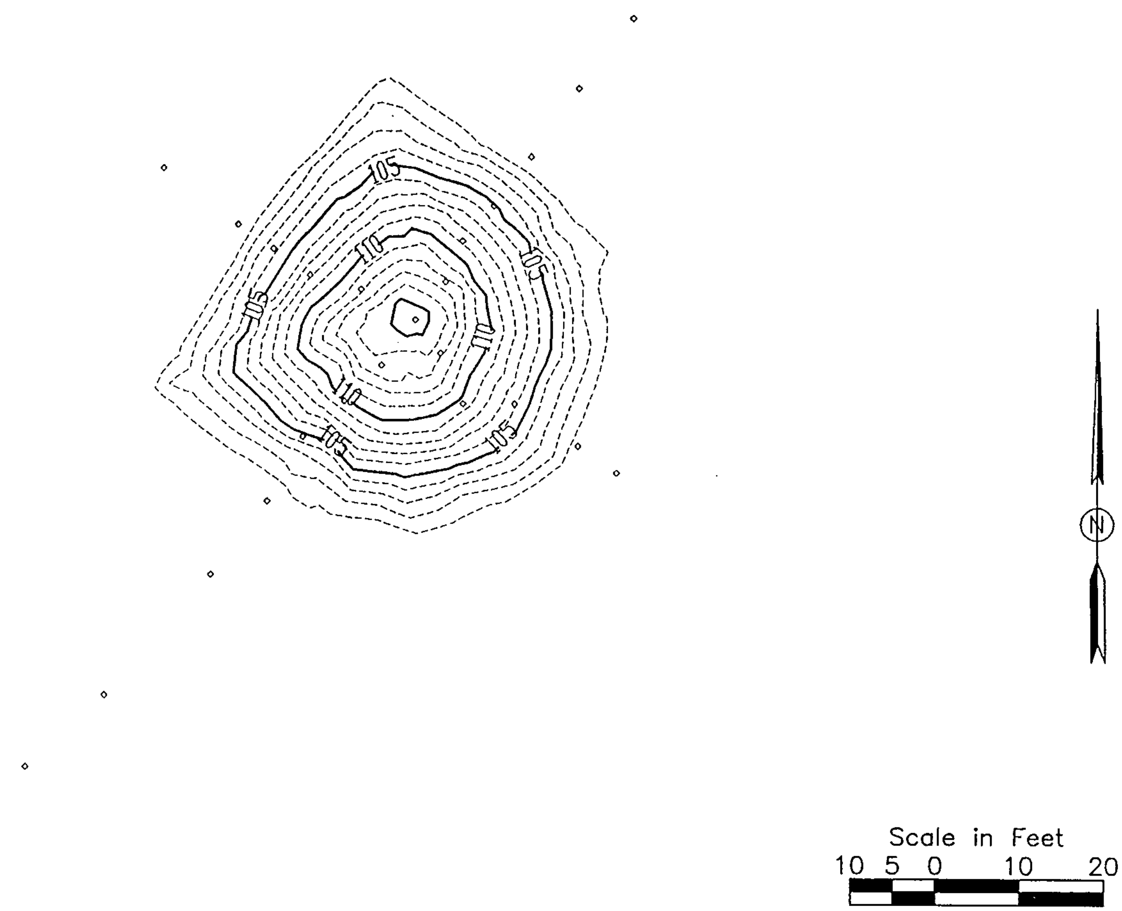


Figure C-7. Pile #3 (2 of 2), Belle Mead Depot, NJ



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 100.4 Ft. as base
Computed Ore Pile Volume: 401.6 Cu.Yds.
Reported Gross Weight: 17,236,526 lbs. (Piles #3A and #3B)

Belle Mead Depot, NJ
Pile #3B, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'
Date: 01 NOV 96

Figure C-8. Elevation contour plot of Pile #3 (2 of 2), Belle Mead Depot, NJ

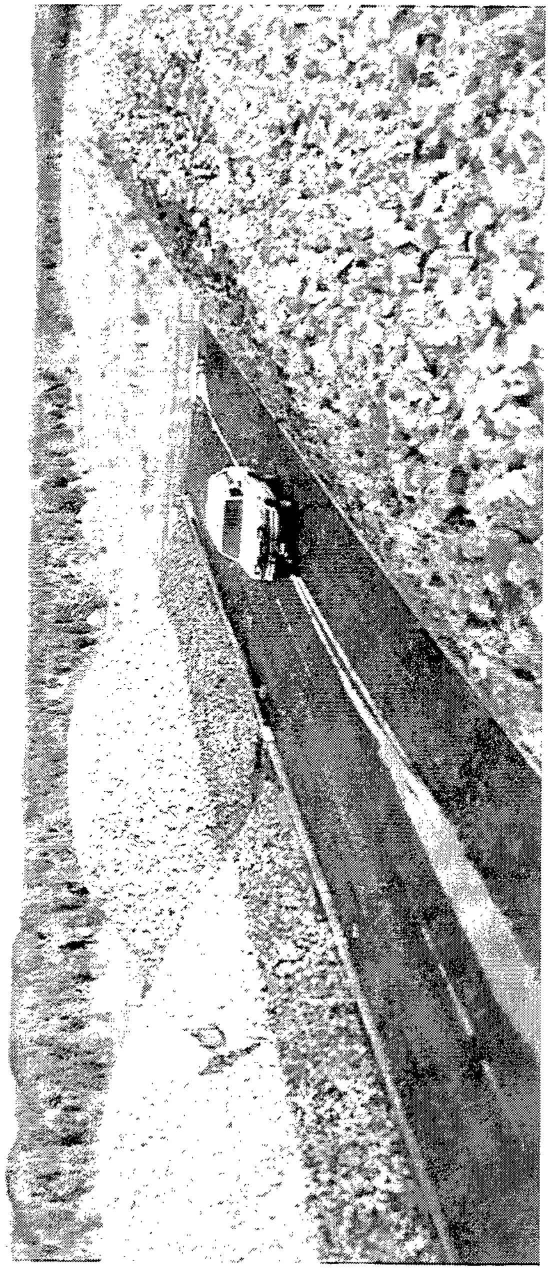


Figure C-9. Pile #4 (1 of 2) (center), Belle Mead Depot, NJ

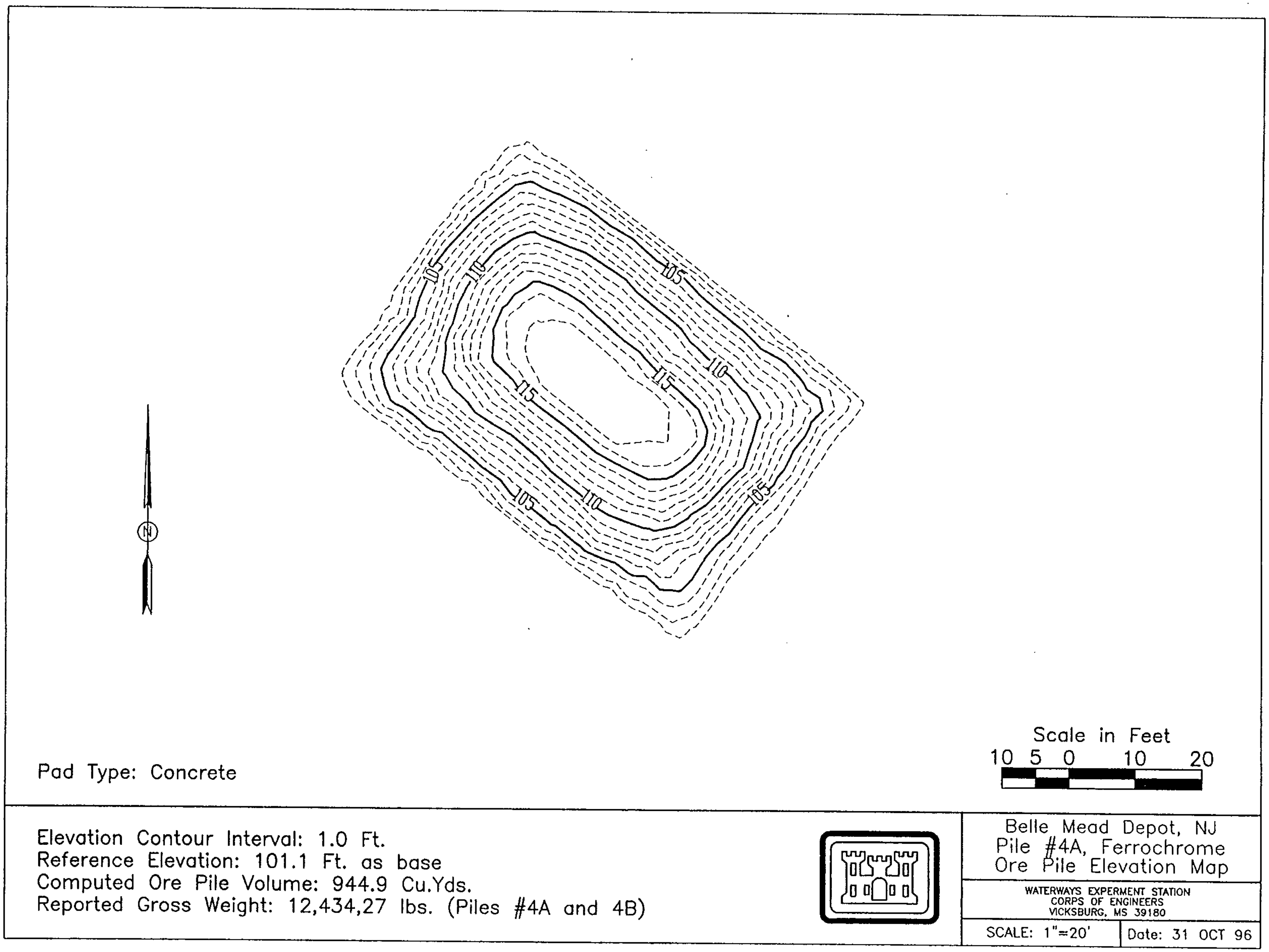


Figure C-10. Elevation contour plot of Pile #4 (1 of 2), Belle Mead Depot, NJ

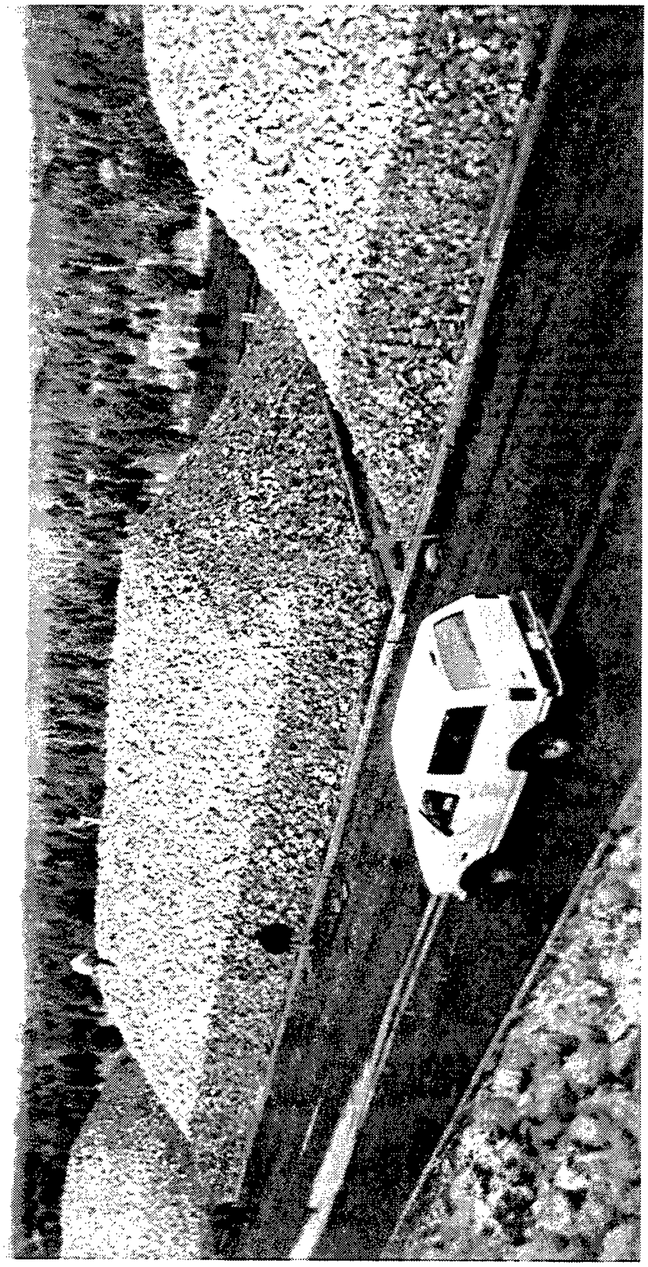


Figure C-11. Pile #5, Belle Mead Depot, NJ

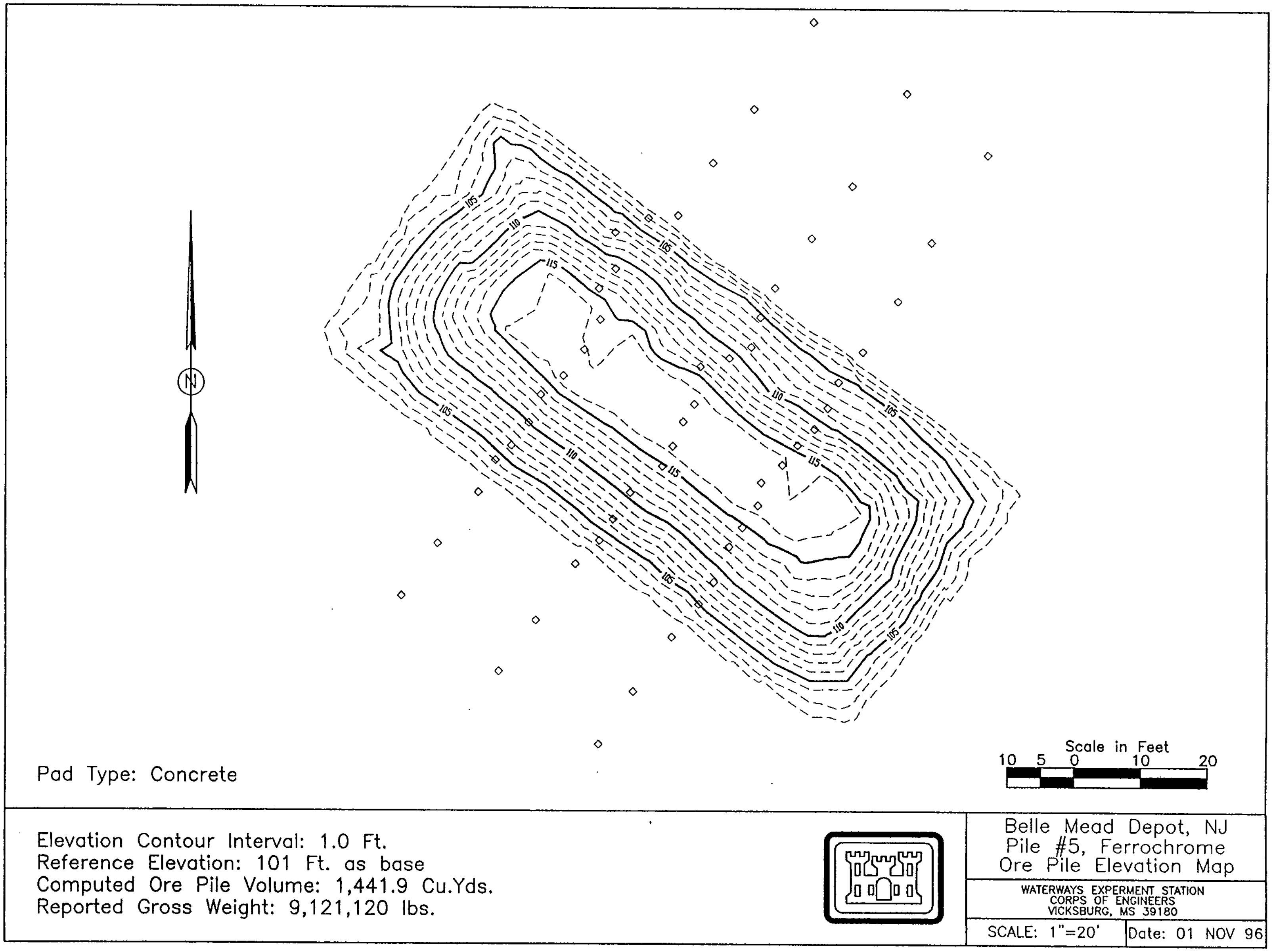


Figure C-12. Elevation contour plot of Pile #5, Belle Mead Depot, NJ

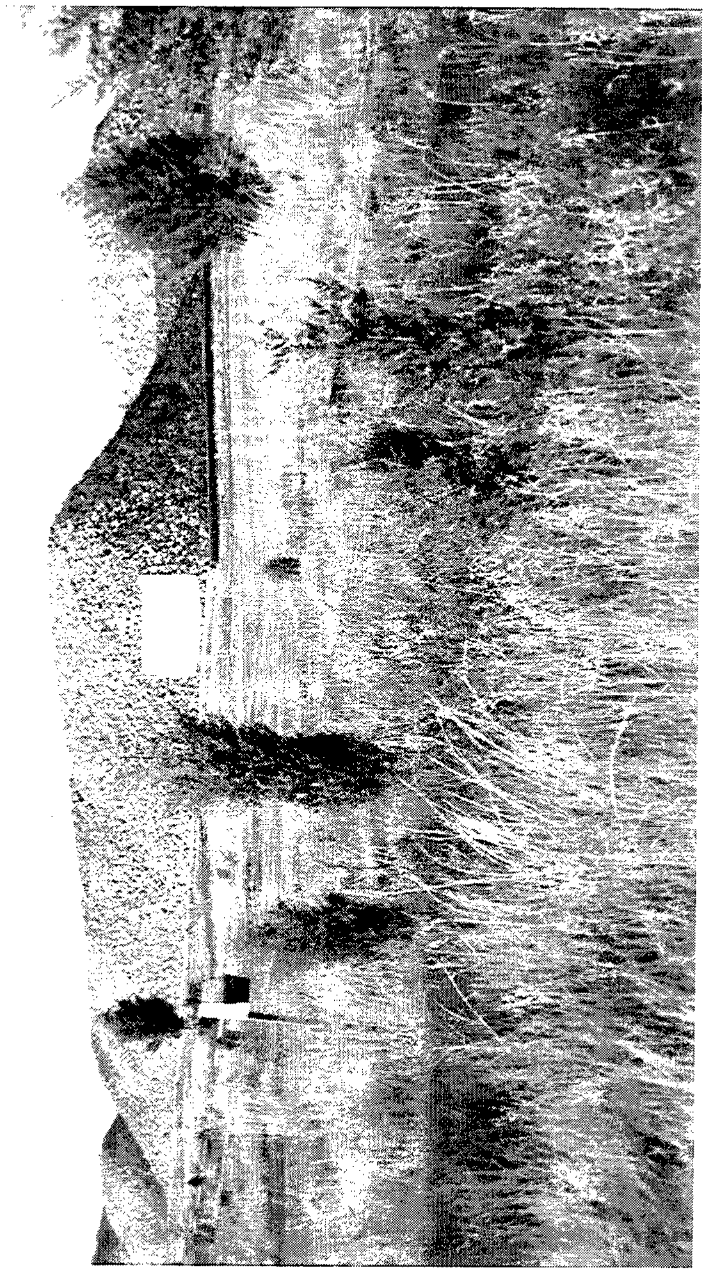


Figure C-13. Pile #6, Belle Mead Depot, NJ

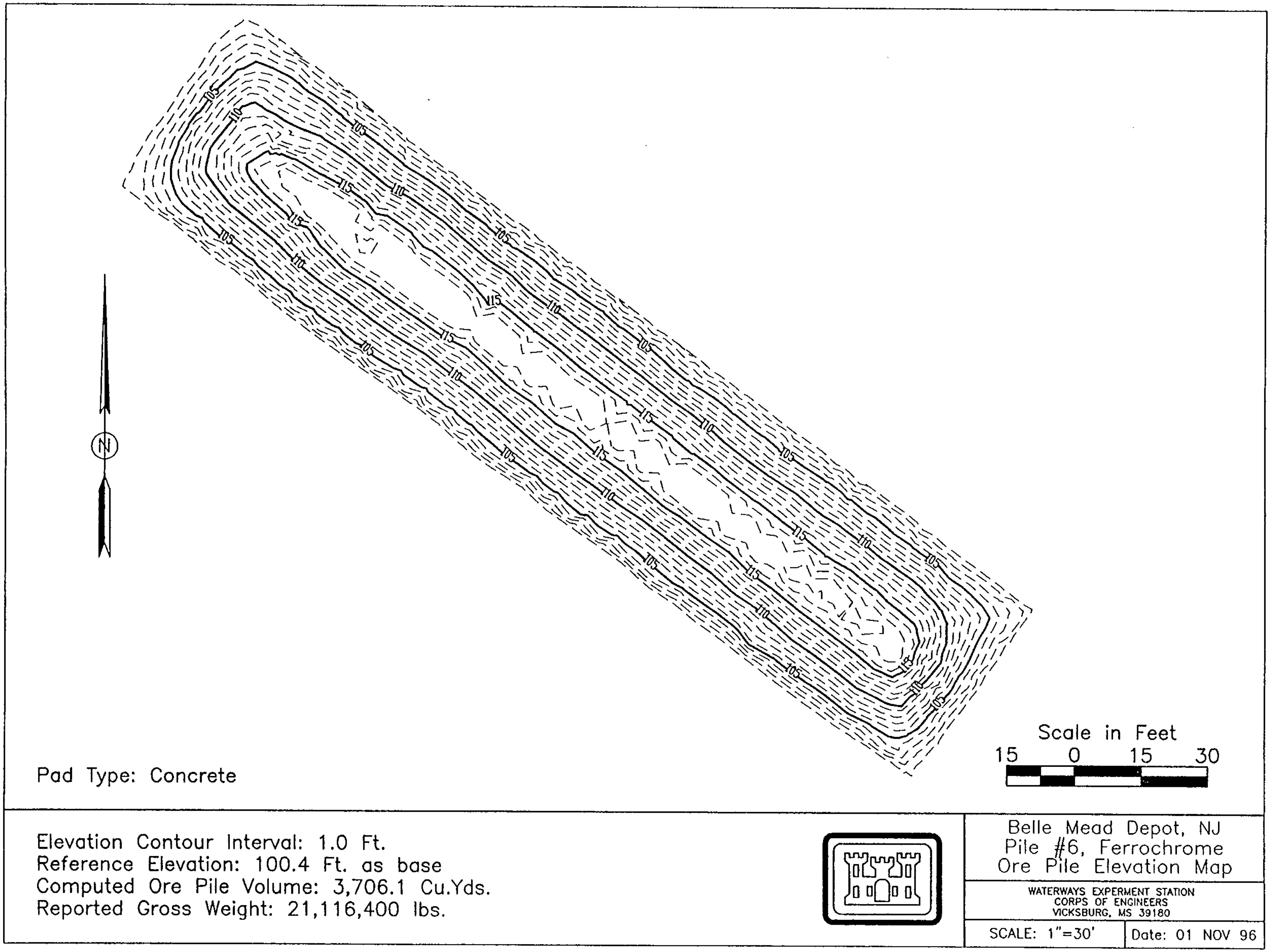


Figure C-14. Elevation contour plot of Pile #6, Belle Mead Depot, NJ

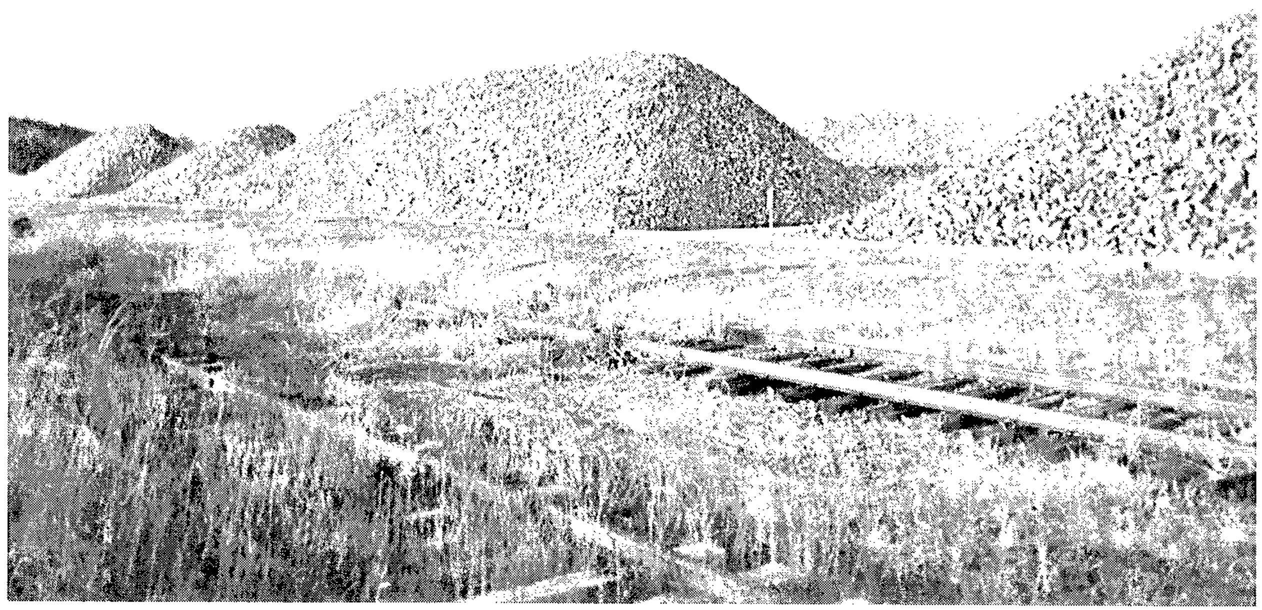


Figure C-15. Piles #8 (center), #3 (2 of 2), and #4 (2 of 2) (far left), Belle Mead Depot, NJ

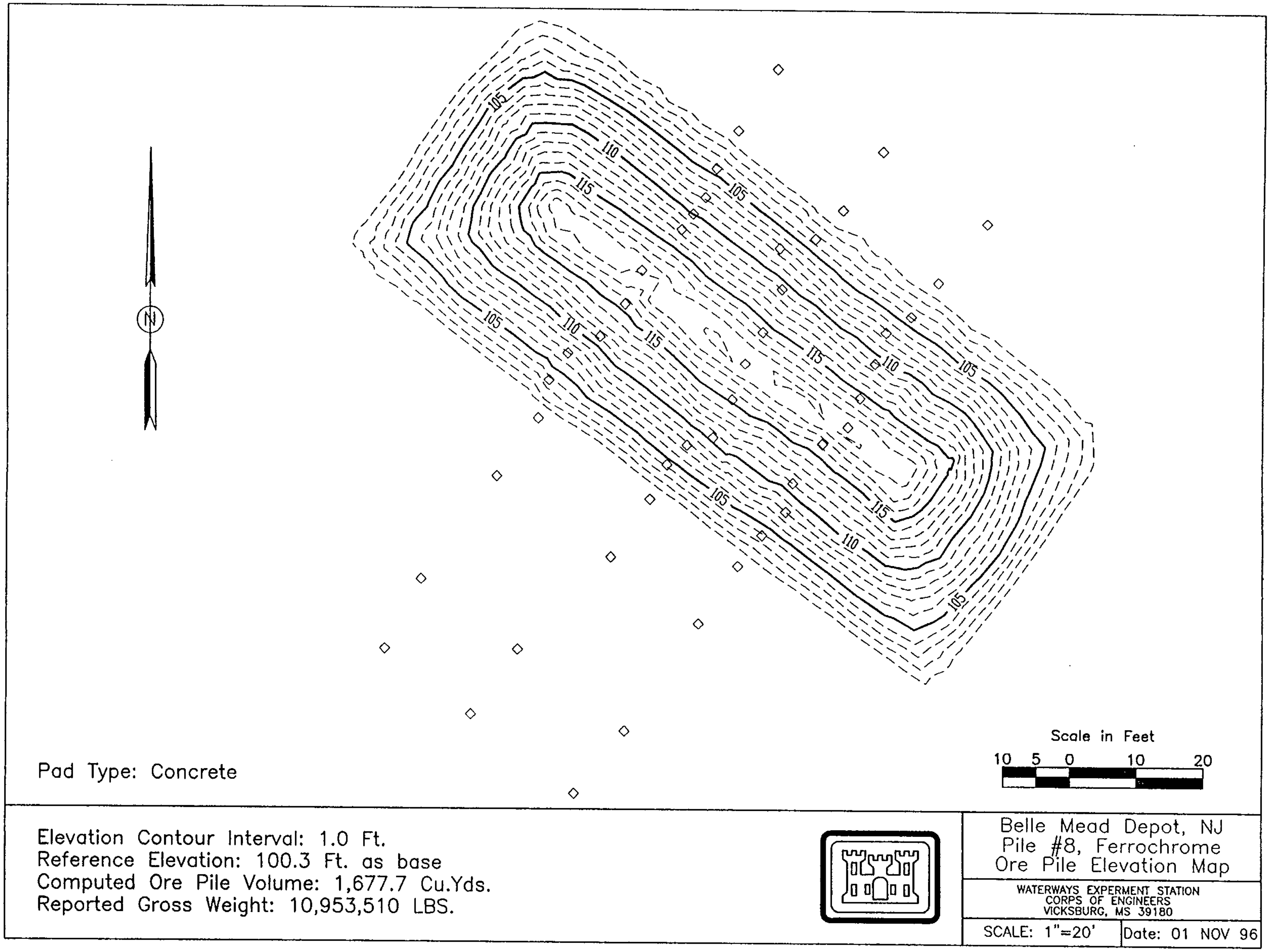


Figure C-16. Elevation contour plot of Pile #8, Belle Mead Depot, NJ

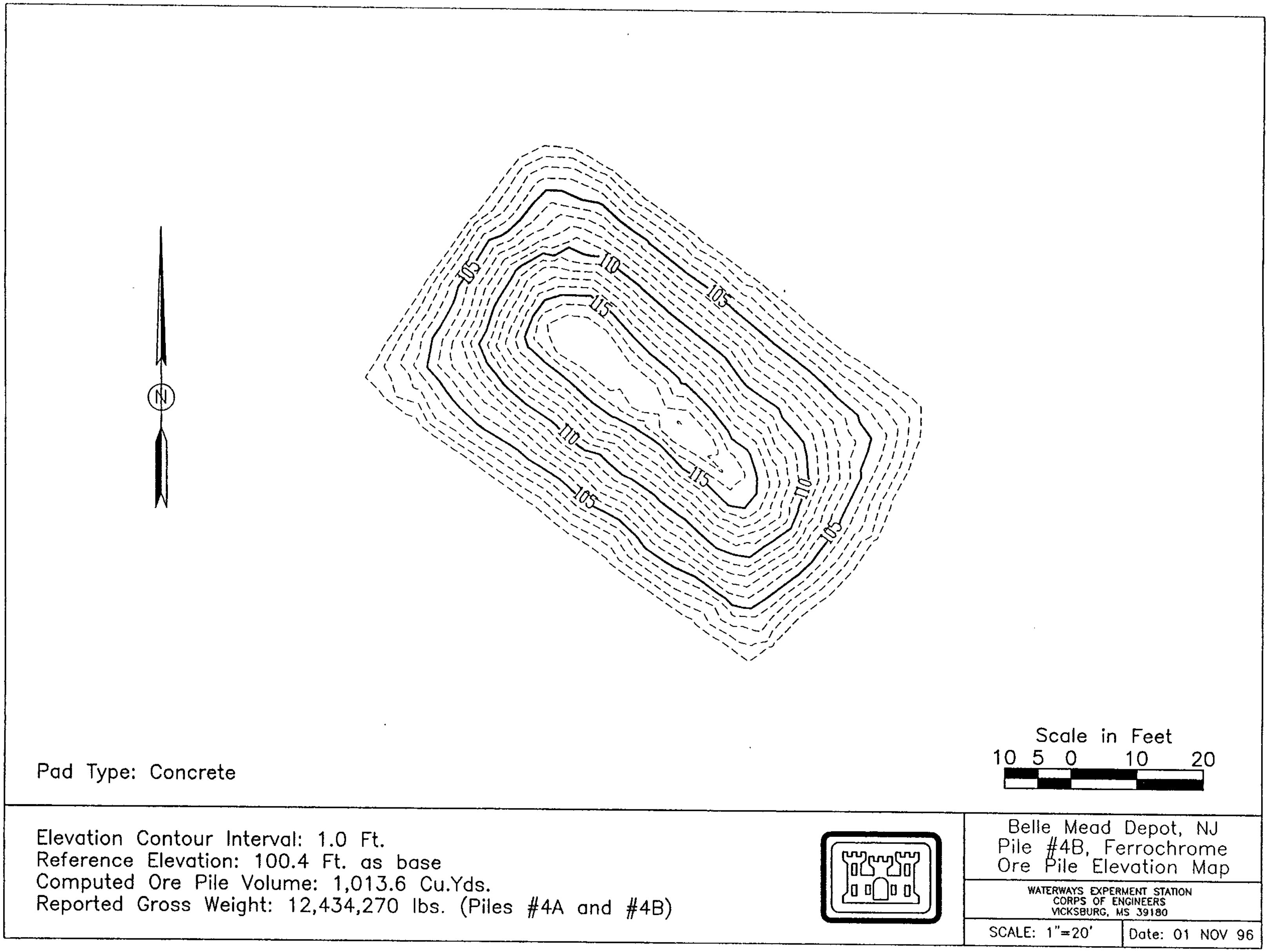
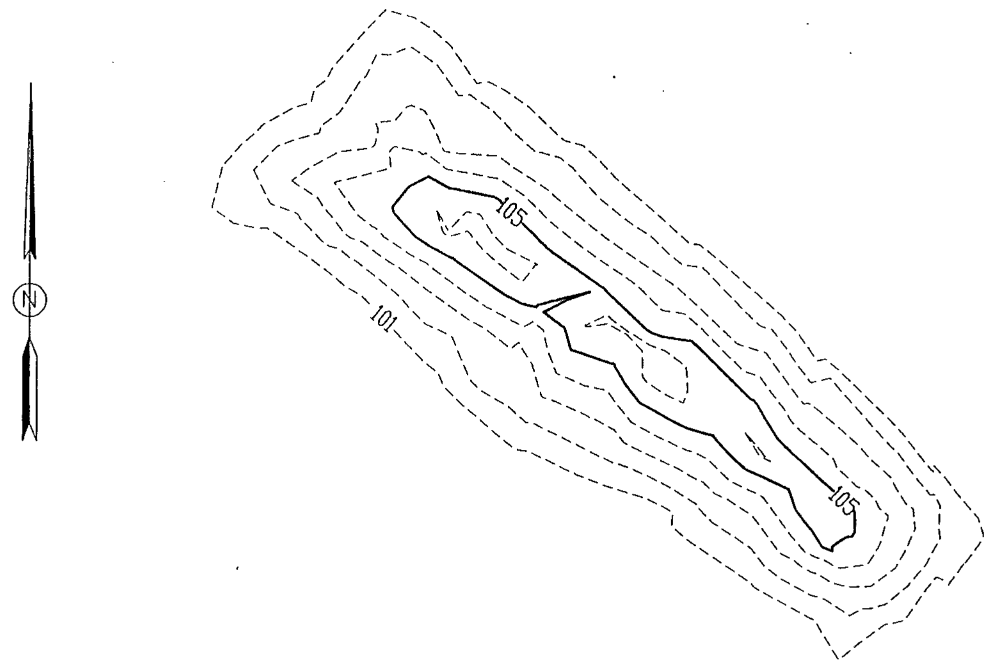


Figure C-17. Elevation contour plot of Pile #4 (2 of 2), Belle Mead Depot, NJ

High-Carbon Ferromanganese



Scale in Feet

5 2.5 0 5 10

Pad Type: Asphalt over Soil Cement (Deteriorated)

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 100 Ft. as base
Computed Ore Pile Volume: 60.4 Cu.Yds.
Reported Gross Weight: 357,920 lbs.

Belle Mead Depot, NJ
Pile #12, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=10' | Date: 30 OCT 96

Figure C-18. Elevation contour plot of Pile #12, Belle Mead Depot, NJ

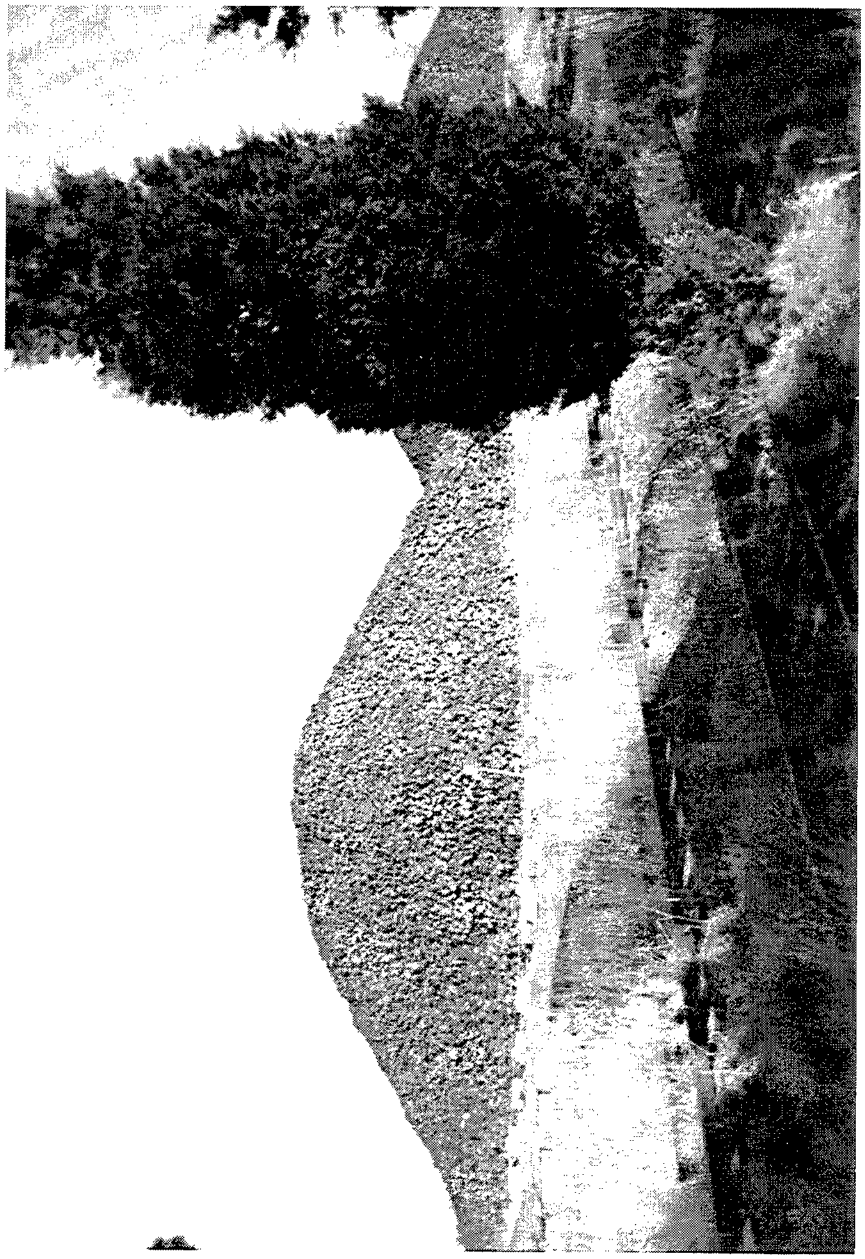
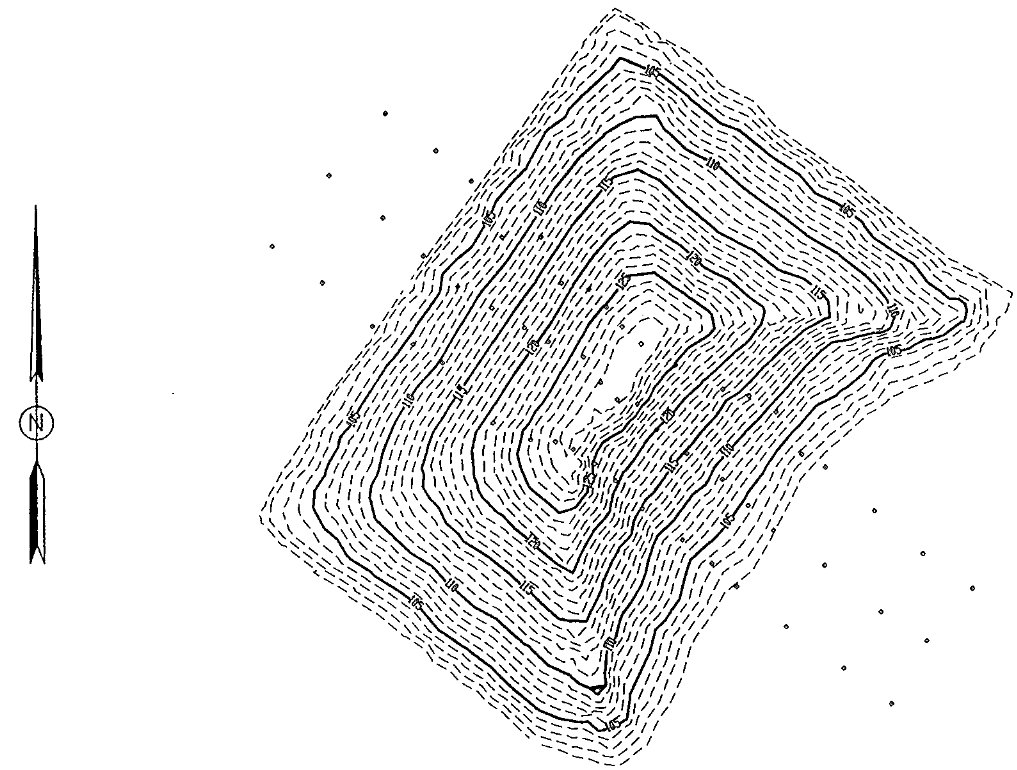


Figure C-19. View looking east towards Pile #16, Belle Mead Depot, NJ



Scale in Feet

15 0 15 30

Pad Type: Asphalt over Soil Cement (Deteriorated)

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 100 Ft. as base
Computed Ore Pile Volume: 3,945.9 Cu.Yds.
Reported Gross Weight: 26,422,660 lbs.

Belle Mead Depot, NJ
Pile #16, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=30' | Date: 03 NOV 96

Figure C-20. Elevation contour plot of Pile #16, Belle Mead Depot, NJ

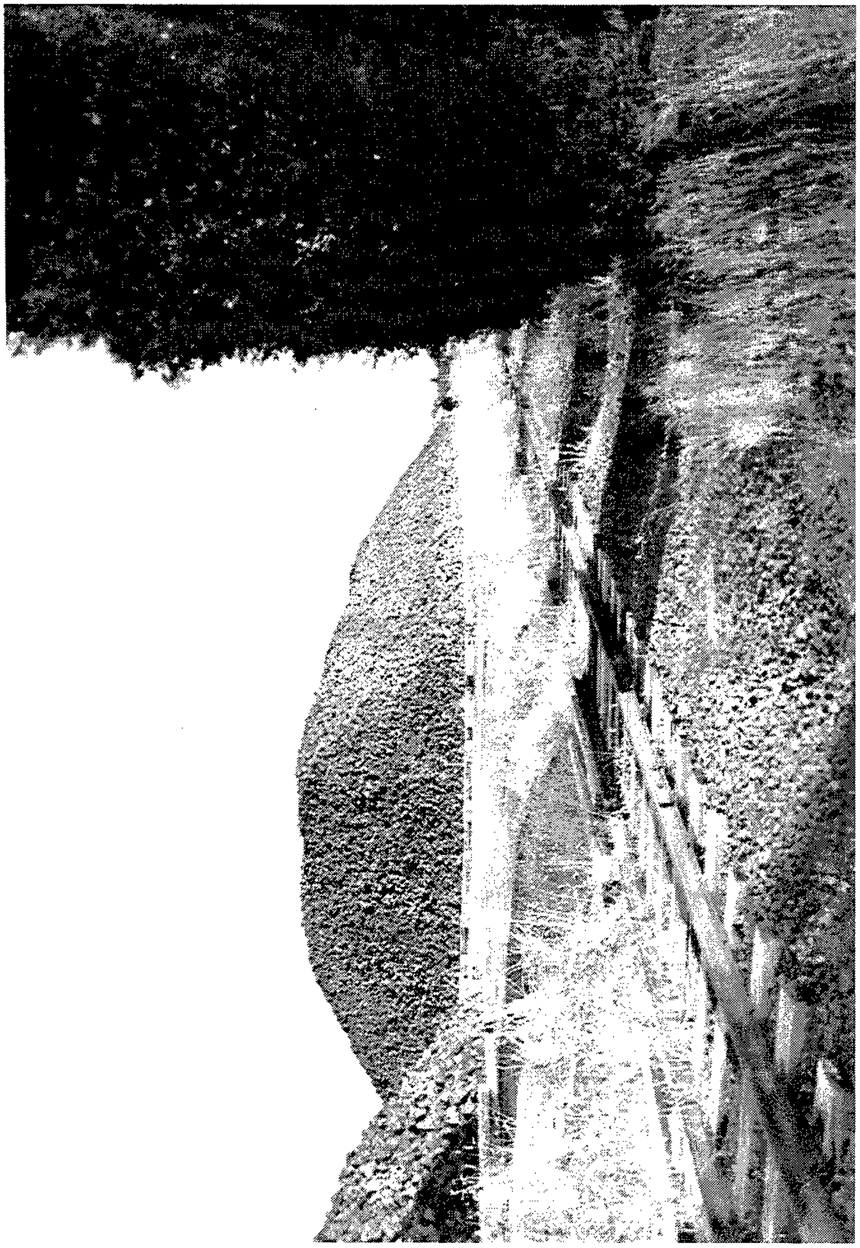
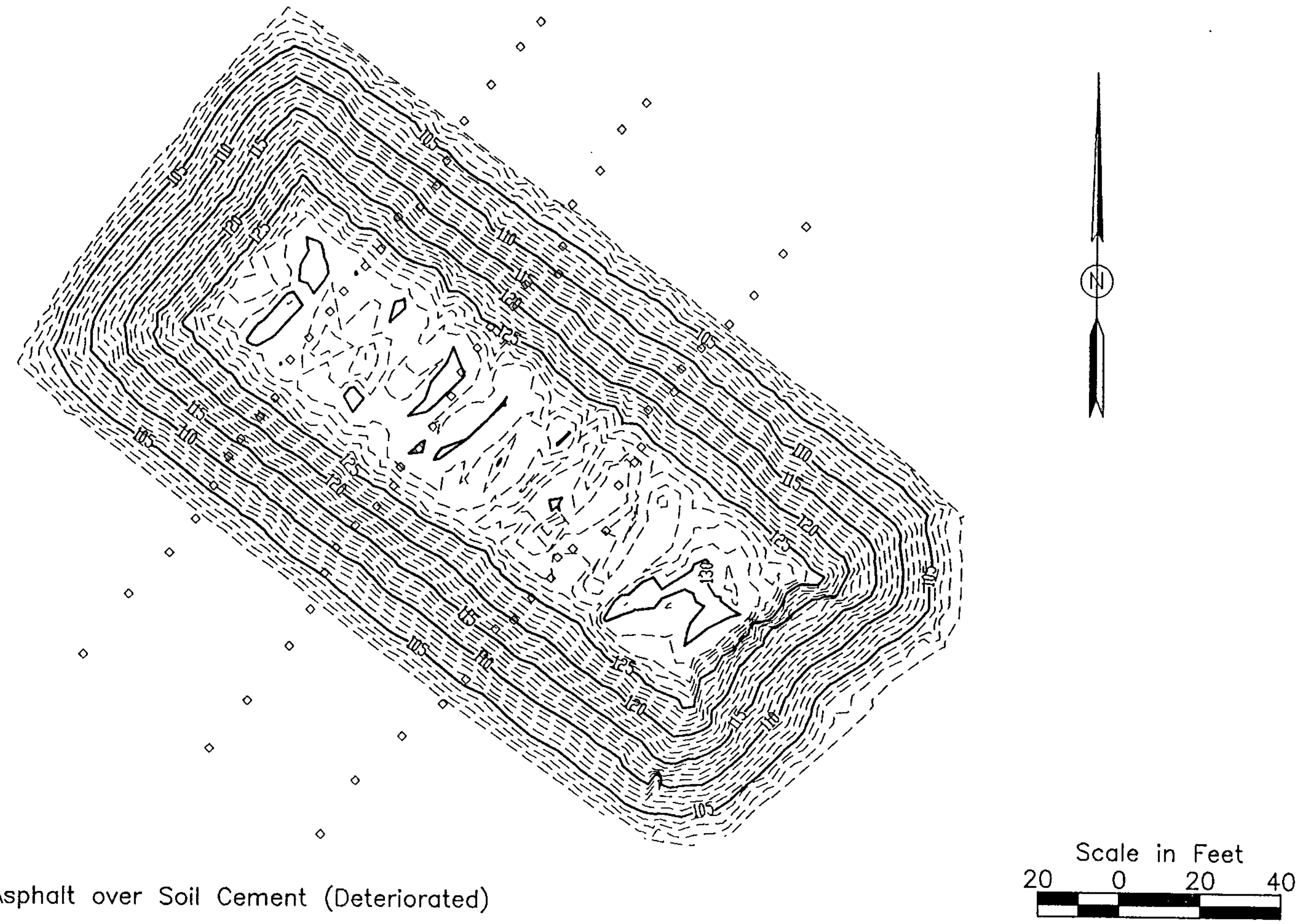


Figure C-21. View looking east towards Pile #18, Belle Mead Depot, NJ



Pad Type: Asphalt over Soil Cement (Deteriorated)

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 100 Ft. as base
Computed Ore Pile Volume: 15,479.3 Cu.Yds.
Reported Gross Weight: 105,729,960 lbs.

Belle Mead Depot, NJ
Pile #18, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=40' | Date: 29 NOV 96

Figure C-22. Elevation contour plot of Pile #18, Belle Mead Depot, NJ

Appendix D Ore Pile Elevation Contour Plots and Photographs, Somerville Depot, NJ

Figure D-1. Piles #3 (foreground) and #4, Somerville Depot, NJ

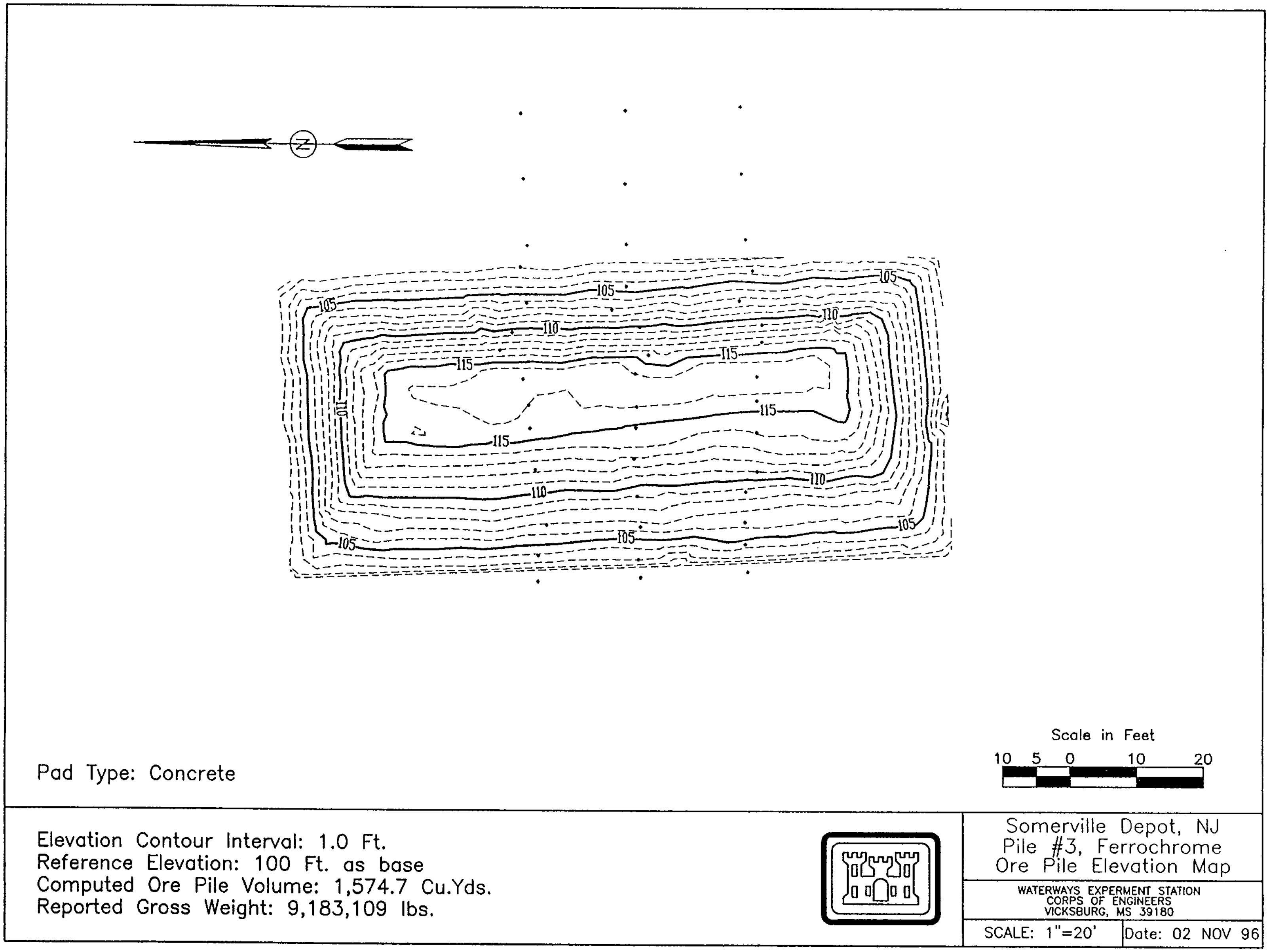


Figure D-2. Elevation contour plot of Pile #3, Somerville Depot, NJ

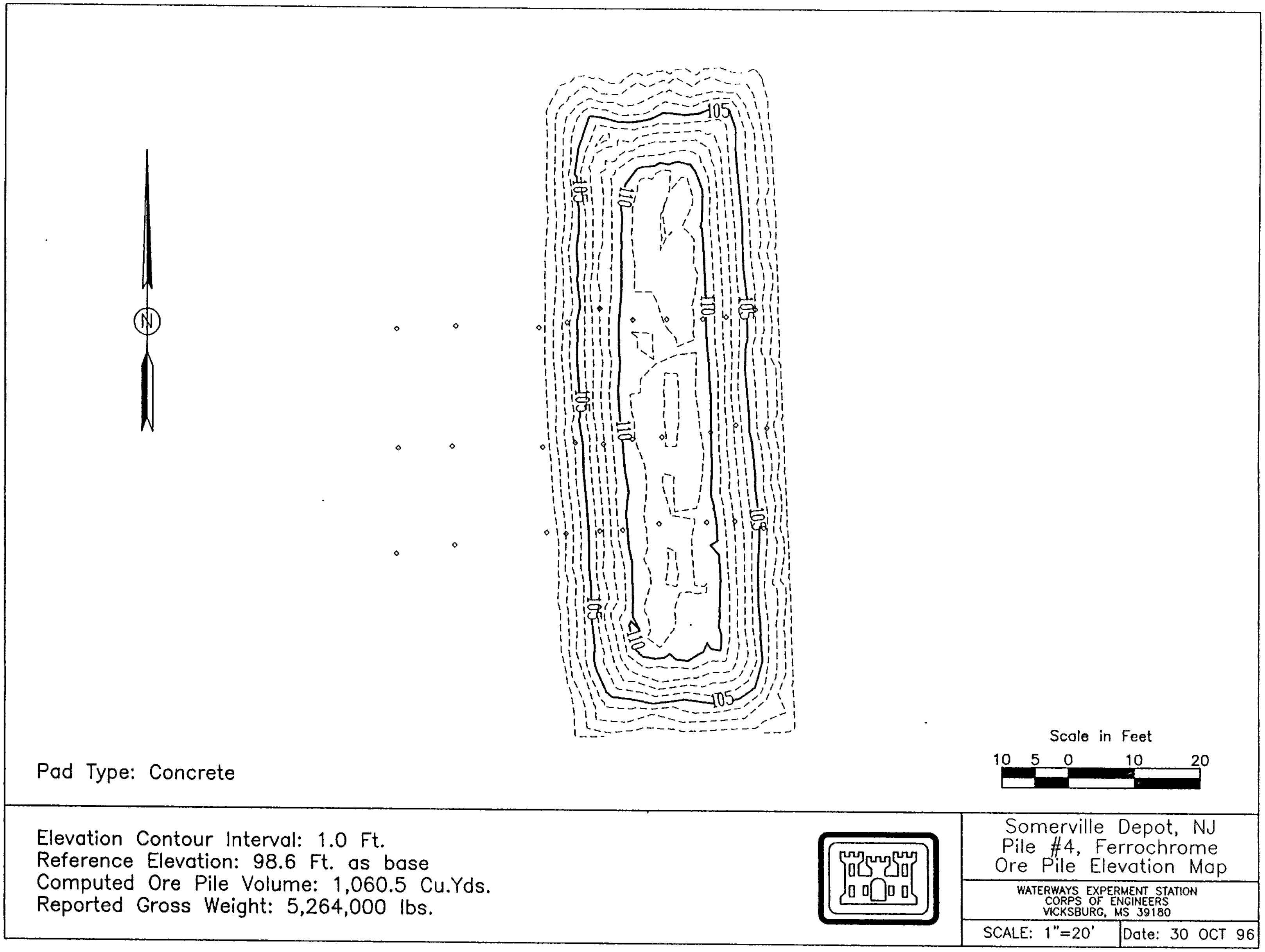


Figure D-3. Elevation contour plot of Pile #4, Somerville Depot, NJ

Appendix E
Ore Pile Elevation Contour Plots and Photographs, Stockton Depot, CA

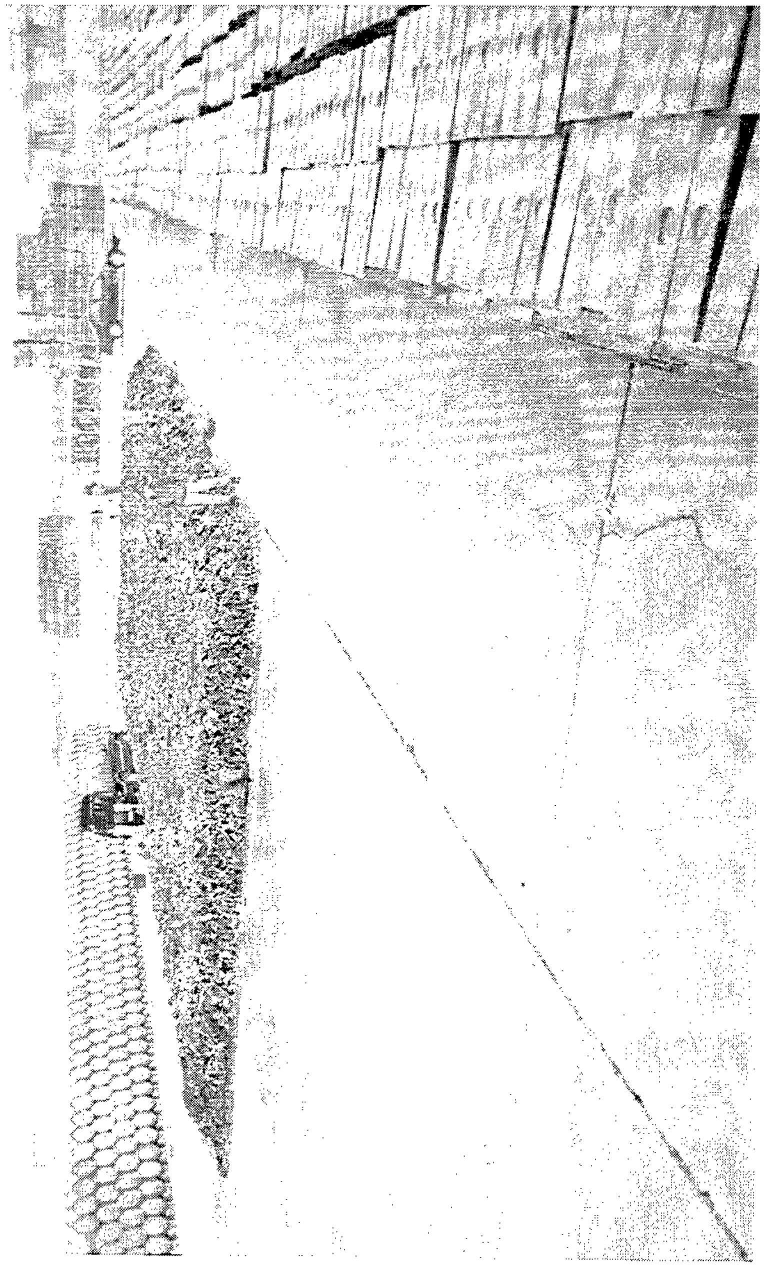


Figure E-1. Pile #1, Stockton Depot, CA

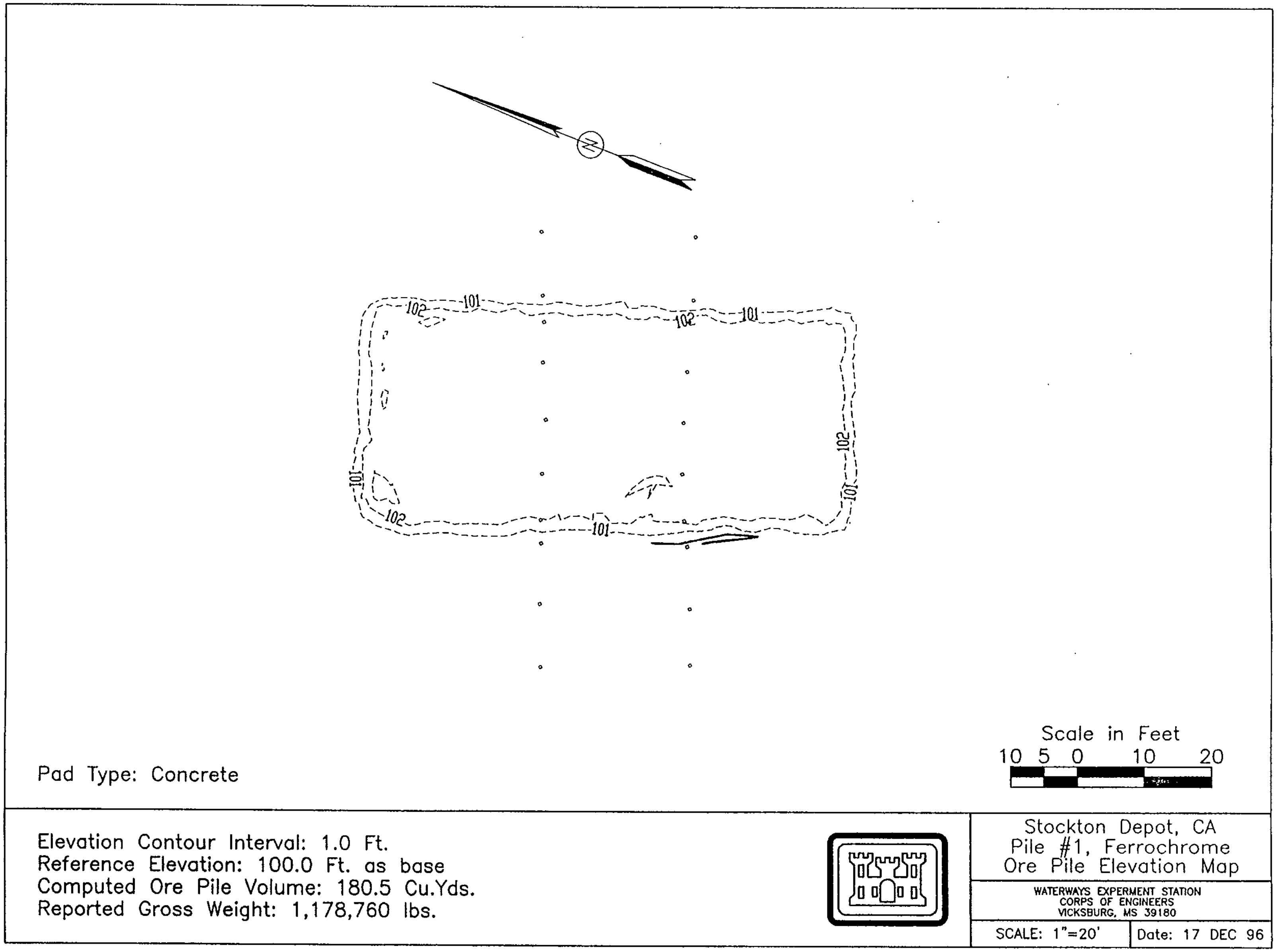


Figure E-2. Elevation contour plot of Pile #1, Stockton Depot, CA

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13. ABSTRACT *(Maximum 200 words)*

The Defense National Stockpile Center (DNSC) maintains stockpiles of high-grade ores at various locations throughout the country and has a requirement to produce current weight estimates for selected piles as part of a national audit. The ore piles for this study are located at the Seneca Army Depot, NY; Stockton Depot, CA; Somerville and Belle Mead Depots, NJ; and Large, PA. Microgravity measurements were performed over selected ore piles to provide high-resolution surveys of the gravitational field with which to determine the average bulk density of the ore material. Parasnis' method was used to analyze the gravity anomaly data. Ore pile volumes were determined using standard land surveying methods. The computed weights for each ore stockpile are compared to the DNSC reported weights and the differences should be within 10 and 15 percent. Results of this investigation indicated that the computed weights of 24 of the 45 piles surveyed are below or within the expected percent difference error range. Seventeen ore piles have differences ranging from 15 to 25 percent and four stockpiles had differences greater than 25 percent of the reported values.

The greatest differences were computed over piles in which settlement of the ore material below the ground surface had taken place or site conditions were such that definition of the true pile base was poor.

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Microgravity
Ore stockpiles

15. NUMBER OF PAGES
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